The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association

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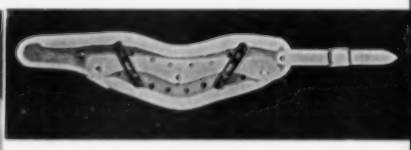

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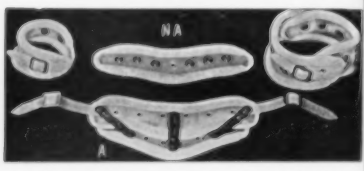

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Vare, V. B.: Medical Forum, Mod. Med. 27:33, 1959.

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Buxton, St. J. D.: Arthroplasty, J. B. Lippincott Co., Philadelphia, 1955, p. 111.

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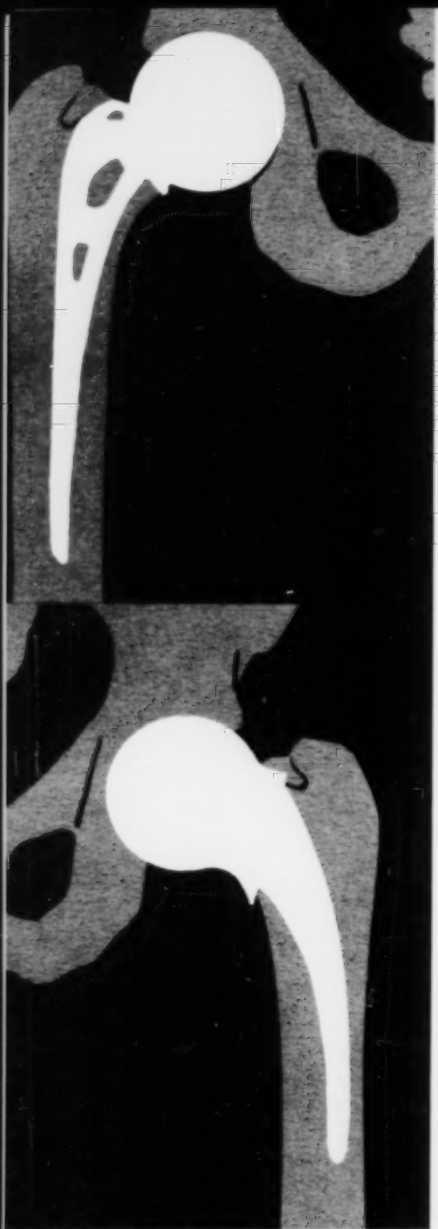

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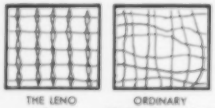

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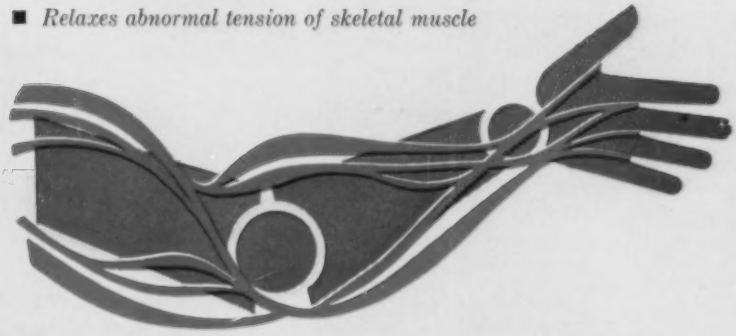

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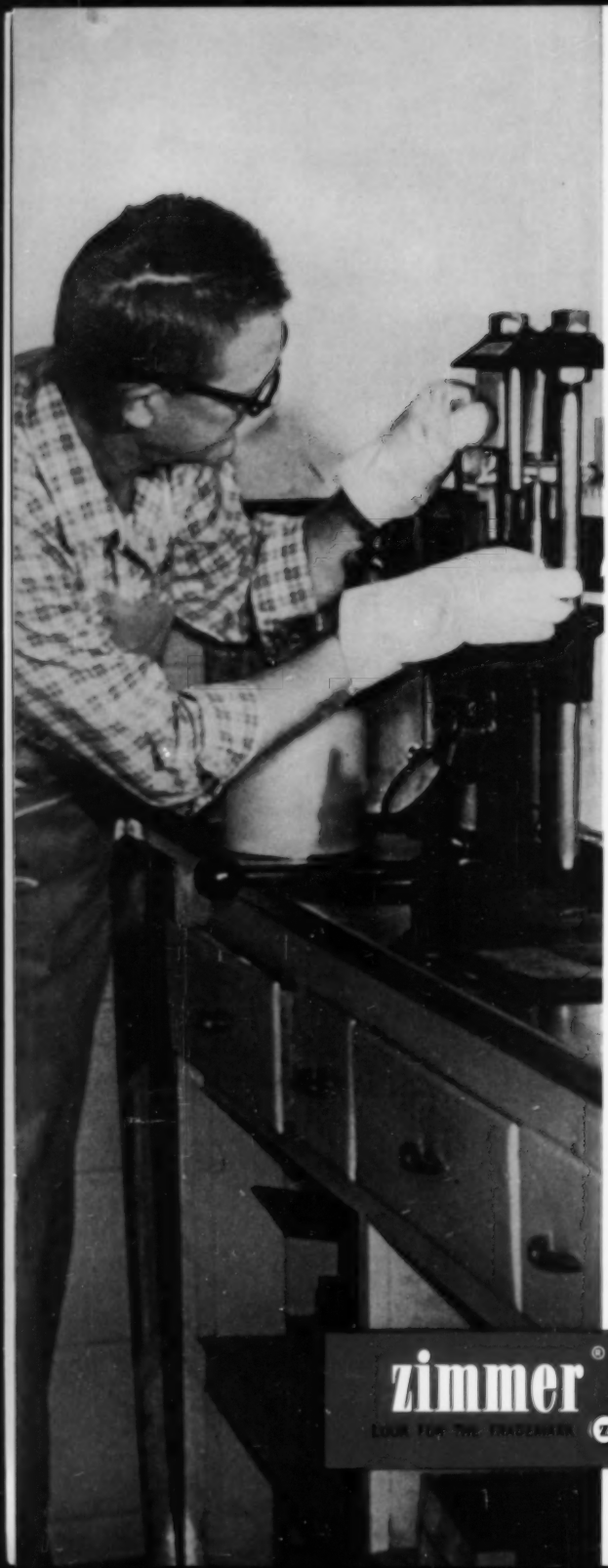

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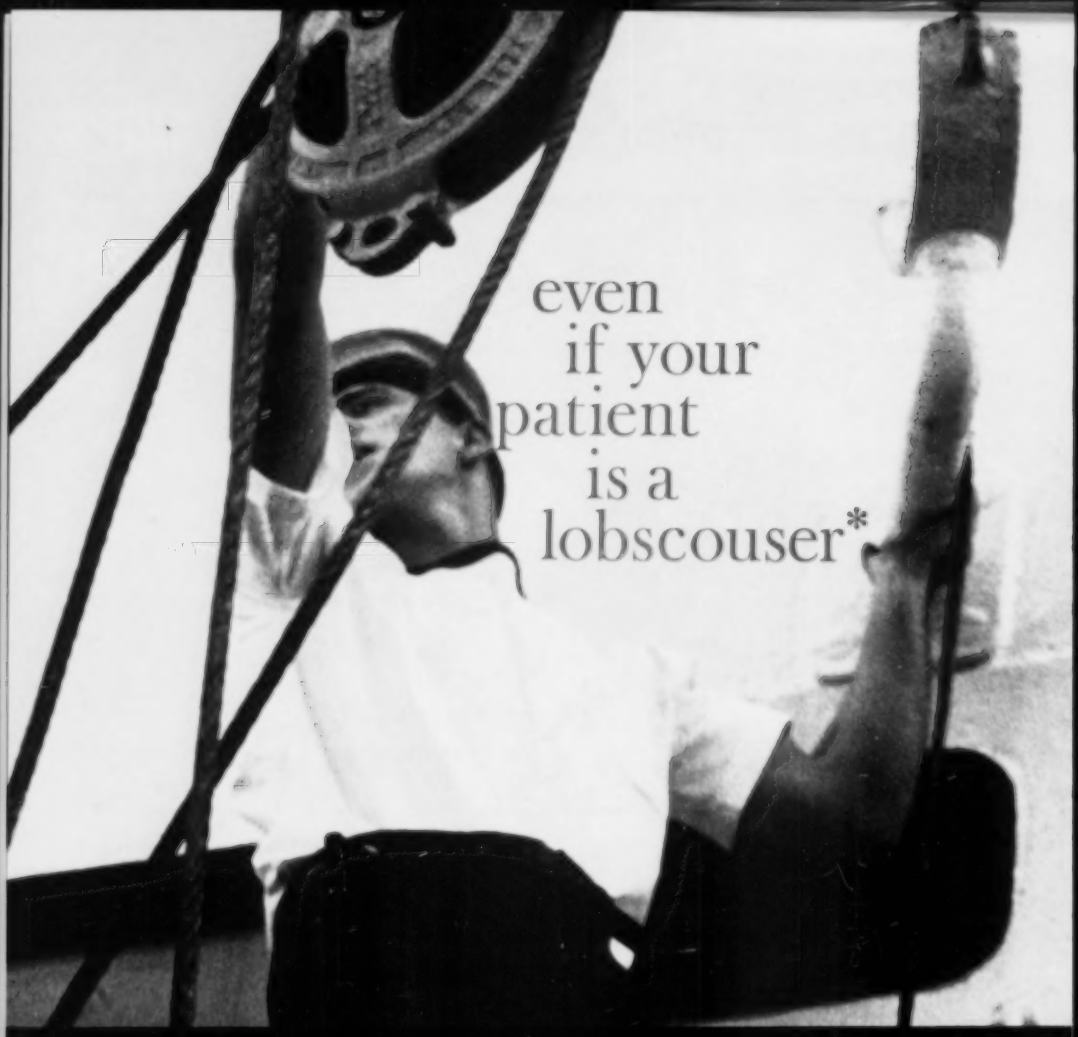

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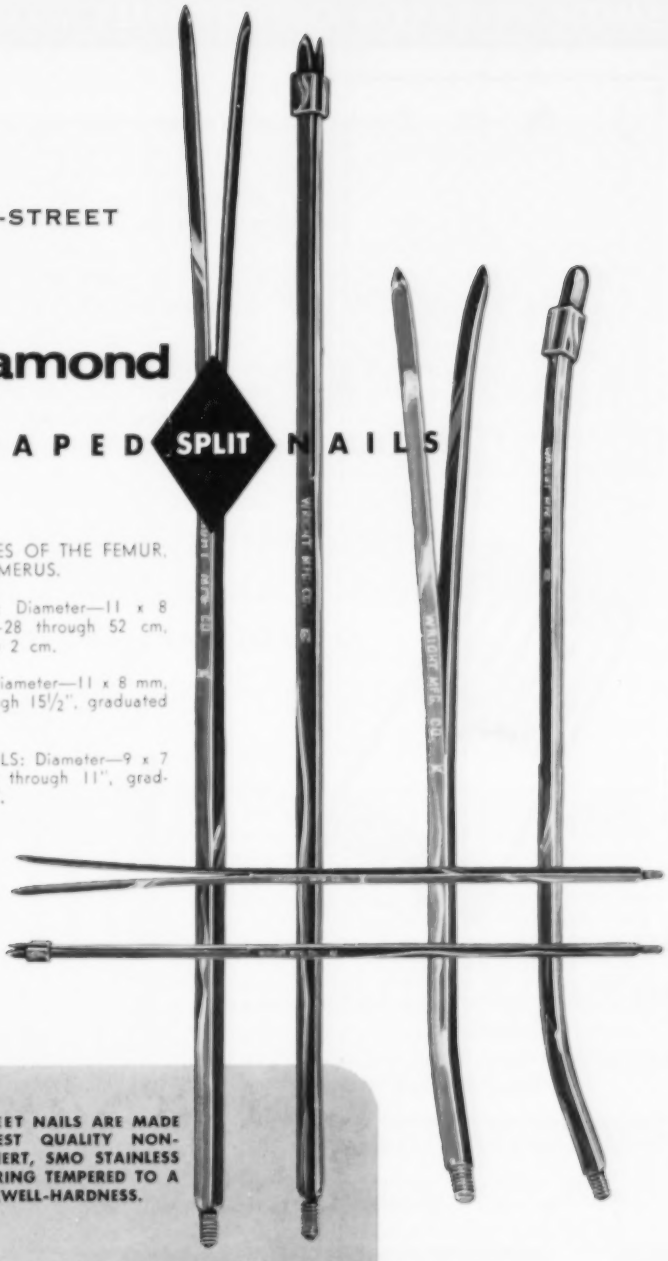


FOR FRACTURES OF THE FEMUR, TIBIA AND HUMERUS.

FEMUR NAILS: Diameter—11 x 8 mm, lengths—28 through 52 cm, graduated every 2 cm.

TIBIA NAILS: Diameter—11 x 8 mm, lengths—9 through 15½", graduated every ½".

HUMERUS NAILS: Diameter—9 x 7 mm, lengths—8 through 11", graduated every ½".

VESELY-STREET NAILS ARE MADE OF THE FINEST QUALITY NON-MAGNETIC, INERT, SMO STAINLESS STEEL . . . SPRING TEMPERED TO A SPECIAL ROCKWELL-HARDNESS.

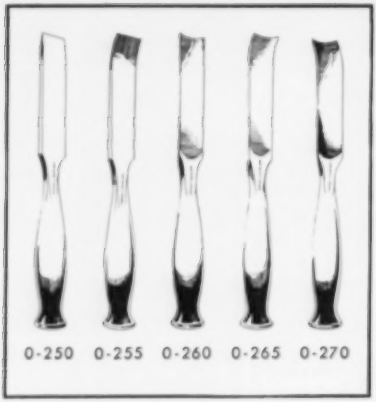
When inserting the Vesely-Street Nail the spring action of the 7" split portion spreads, thereby preventing rotation and giving maximum strength. (Technique upon request.)

WRIGHT MANUFACTURING CO.

880-882 ADAMS AVENUE • MEMPHIS 3, TENNESSEE

WRITE TO DEPT. V-1 FOR FURTHER INFORMATION AND NEW CATALOG

SMITH-PETERSEN OSTEOTOMES and GOUGES



0-250 SMITH-PETERSEN OSTEOTOME—straight, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

0-255 SMITH-PETERSEN OSTEOTOME—curved, 8", sizes ¼", ⅜", ½", ⅝", ¾", 1" and 1¼". Stainless Steel.

0-260 SMITH-PETERSEN GOUGE—straight, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

0-265 SMITH-PETERSEN GOUGE—curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

0-270 SMITH-PETERSEN GOUGE—reverse curved, 8", sizes ⅜", 9/16", ¾" and 1". Stainless Steel.

A NEW STAINLESS STEEL CASE TO HOLD SMITH-PETERSEN OSTEOTOMES and GOUGES

0-295 Open

CASE 0-295—holds seven Smith-Petersen Osteotomes.

CASE 0-296—holds seven Smith-Petersen Gouges.

CASE 0-297—holds a combination of seven Osteotomes and Gouges.

Cutting edges are protected at all times. Complete unit may be autoclaved.

0-295 Closed

Specify Width of Gouges and Osteotomes When Ordering

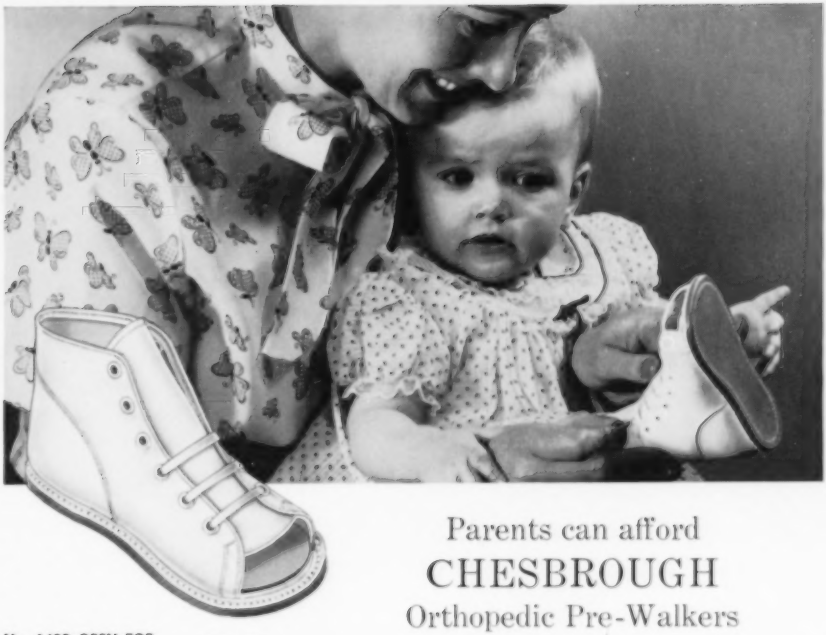
ESTABLISHED 1838

Codman & Shurtleff, Inc.

MAKERS OF SURGEONS' INSTRUMENTS

104 BROOKLINE AVENUE BOSTON 15, MASSACHUSETTS

In answering advertisements, please mention *The Journal of Bone and Joint Surgery*.



Parents can afford
CHESBROUGH
Orthopedic Pre-Walkers

No. 1400 OPEN TOE
Straight-line symmetrical last, firm heel, no back seam. Adaptable to Denis Browne Splints.

No. 1300 CLOSED TOE
Lace-to-toe design permits snug, gentle fit. Perfectly smooth inside.

No. 1700 CLUBFOOT, OPEN TOE
Special outflare last, sturdy instep strap to stabilize heel.

Louis C. Weld, President of G. W. Chesbrough Co. . . . "My own personal experience led to the development of the new Chesbrough Shoe."

Here are Orthopedic infants' shoes that meet rigid requirements of corrective footwear yet fit the family budget.

High-quality workmanship and fine leathers with orthopedically correct lasts are combined in Chesbrough Shoes to sell at a moderate price.

Any parent whose child requires orthopedic correction knows the expense is great, as frequent purchase of new shoes is required.

This problem was brought home to Chesbrough's president, Louis C. Weld, three years ago, when a child in his own family needed such a shoe. Recognizing the need for orthopedic shoes at an economical price, Chesbrough Company put their 60 years of shoemaking experience to work and Chesbrough Corrective Pre-Walker Shoes were born.

All shoes in unlined white elk, sizes 000 to 4, narrow and wide. Available in full pairs, split pairs or single shoes (no extra charge for half pairs).

MAIL COUPON FOR FREE DESK SAMPLES

G. W. CHESBROUGH CO.
807 Smith Street, Rochester 6, N. Y.

NAME .....

ADDRESS .....

CITY ..... STATE .....

YOUR ORTHOPEDIC SHOE DEALER:

.....

ANNOUNCING
SCHERING'S
NEW
MYOGESIC[X]

RELA™ EASES STRAINS
SPRAINS & LOW
BACK PAINS...!

X

CARISOPRODOL

RELA—a new myogesic for better relaxant *and* analgesic therapy—more adept management of spasm and pain in strains, sprains and low back pains.

RELA—though a single drug—is a true myogesic and works rapidly to achieve three desired effects...

Rela relaxes acute muscle spasm
Relief of muscle spasm (96% excellent to good effectiveness)[1]

Rela provides a unique quality of persistent pain relief through its relaxant and analgesic actions
"Relief from pain was usually rapid and sometimes dramatic"[1]

Rela, through relaxation and analgesia, assures daytime ease and nighttime rest
"... A number of patients reported freedom from insomnia which they attributed to freedom from pain."[1]

indications: RELA is most beneficial in those conditions of the musculoskeletal system manifesting pain, stiffness and spasm.

safety: Studies of more than 1400 patients indicate that the toxicity of RELA is exceptionally low. In human subjects, respiratory, blood pressure or blood chemistry changes and/or renal, hepatic or endocrine dysfunction have not been reported.

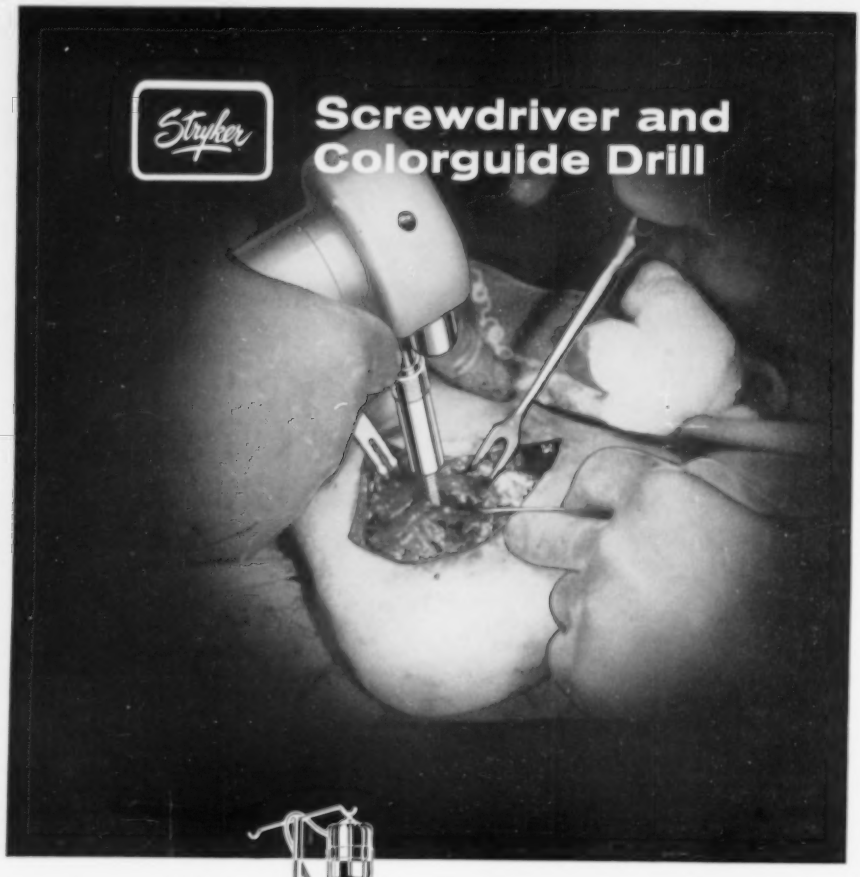
dosage: The usual adult dosage of RELA is one tablet 3 times daily and at bedtime. RELA has a rapid onset of action, with relief usually apparent within 30 minutes, and persisting for at least 6 hours.

supply: RELA is available as 350 mg., pink, coated tablets in bottles of 30.

1. Kuge, T.: To be published.

xMYOGESIC
muscle–analgesic relaxant

Schering



Handpieces for the Stryker Electro-Surgical Unit . . .

- Bone Saw
- Rolo-Dermatome
- Sagittal Saw
- Pencil-Grip Burring Handpiece
- Bone Drill Handpiece
  - Automatic Screwdriver
  - Colorguide Drill
  - Jacobs Chuck
- Colorguide Screw Case

Screws are driven in automatically. Color-coded drill determines depth of hole.

The lightweight handpiece is geared to slow speed and operates not only the Drill and Screwdriver, but also a ¾" Jacobs Chuck. The colorguide on the drill shaft accurately indicates the depth of hole drilled for quick selection of correct screw length by color from screw case.

Screws are inserted or removed by using the clockwise or counter-clockwise shaft in the drill head.

Ask for the Colorguide Drill and/or Screwdriver on approval. Call, wire or write today.

Stryker

SURGICAL AND HOSPITAL EQUIPMENT

Orthopedic Frame Company

420 ALCOTT STREET • KALAMAZOO, MICHIGAN

Exclusive Agent for Export: Schueler & Co., 75 Cliff St., N. Y.

SUSAN, THE TECHNICIAN TELLS HOW:

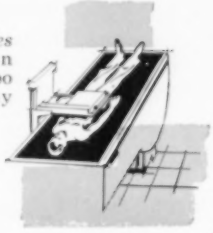
"Patrician's comfort and simplicity please everyone"

"Our radiologist likes the *Patrician* for fluoroscopy. Traded his old unit . . . got rid of tiresome tussles with an awkward fluoroscopic screen."

"Poor Mrs. Smith had tremors — no problem for me, though. The Patrician '200' is built for split-second radiography that really 'stops' motion."

"Miss Jones says she 'feels faint' — I'm glad to know the Patrician handles easily. Switches quickly from fluoroscopy to radiography . . . minimizes examination time for high-strung patients."

"Tall Johnny stretches comfortably. Even 6½ footers are not too big for this roomy 81" table."



• Ask your G-E x-ray representative for full details on Patrician's big-table convenience. Or clip this coupon for a copy of *new* illustrated catalog.

GENERAL ELECTRIC

X-RAY DEPARTMENT
GENERAL ELECTRIC CO.
Milwaukee 1, Wisconsin, Rm. CF-121

Please send me:

- ☐ New 8-page PATRICIAN bulletin
- ☐ Facts about deferred payment
- ☐ MAXISERVICE® all-inclusive rental plan

Name.....

Address.....

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YOU'LL BE GLAD TO PRESCRIBE

Alden-Pedic

SCIENTIFIC CONSTRUCTION SHOES

Style No. 84

Alden-Pedic lasts and shoes are scientifically designed to fit the individual foot shape and at the same time accommodate your prescribed corrections and insertions without sacrificing any fitting qualities. Alden-Pedic shoes are basic prescription shoes. We do not manufacture a pre-corrected or commercial health shoe.

Orthopedic surgeons familiar with the Alden-Pedic program have achieved most satisfactory results in recommending our shoes.

Write us today for our new illustrated brochure of Alden-Pedic styles for men and boys and our new "Progress Report on Shoe and Last Design".

Developed through our modern research program

- Long inside counter
- Right and left ortho heels, long inside
- Heavy gauge right and left ribbed steel shank.
- New "Depth Design" accommodates prescribed corrections

C. H. ALDEN SHOE COMPANY

Custom Bootmakers Since 1884

BROCKTON, MASSACHUSETTS

FOR BOOKLET AND NAME OF NEAREST DEALER WRITE

remember this patient with musculoskeletal pain?

remember PAIN Zactirin®

Ethoheptazine Citrate (75 mg.) with Acetylsalicylic Acid (325 mg.), Wyeth

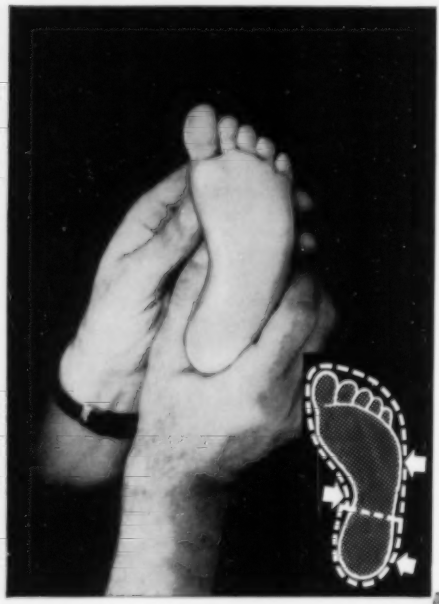
Active now, pain relieved, inflammation controlled, *free of disturbing reactions. . . .* ZACTIRIN offers reliable analgesia plus anti-inflammatory benefits in a wide variety of joint and muscle disorders. It is non-narcotic and nonsteroid. Its relief of pain is equivalent to that of codeine. Yet it is well tolerated in both acute and prolonged use.

Myositis, fibrositis, myalgia, low back pain, ligamental strain, sciatica, bursitis, frozen shoulder, wryneck, osteoarthritis, rheumatoid arthritis, postoperative orthopedics

Supplied: Tablets, bottles of 48.

Wyeth®
Philadelphia 1, Pa.

the action of the TARSO SUPINATOR SHOE

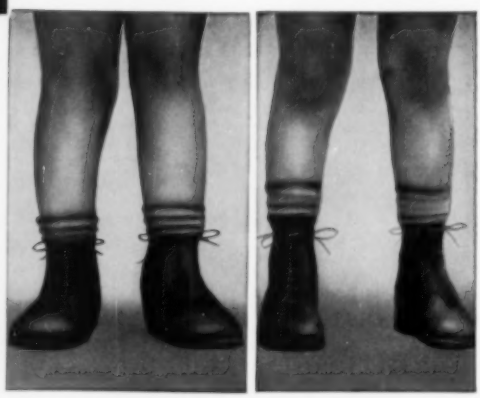


. . . swings the hind-foot inward, which induces adduction of the fore-foot, elevates the longitudinal arch, and levels the ankle joint.

When the hind-foot is held in a position of inward rotation, the talo-scaphoid and cuneiform-scaphoid joints will remain locked under weight bearing. The arch will not collapse and the ankle will not roll inward.

Correction is accomplished by the specially shaped last. Medially wedged and extended heels promote better weight distribution. Medially extended counters are used for utmost control.

See us in Chicago — January 23–28
27th Annual Meeting
American Academy of Orthopaedic Surgeons
BOOTH 30



BEFORE **AFTER**

The Tarso Supinator shoe is used successfully in treatment of the plano-valgus foot. Pronation is controlled at once. Permanent improvements in walking and in foot posture will generally occur. Patients find Tarso Supinators notably comfortable.

Tarso Shoes are ready-made and are available on prescription from dealers in most cities. Write for catalog and name of nearest dealer.

T.S. TARSO SUPINATOR REG. U.S. PAT. OFF. SHOE
FOR FLAT FEET

M. J. MARKELL SHOE COMPANY, INC.

332 SOUTH BROADWAY • YONKERS, NEW YORK

ORIGINATORS OF TARSO PRONATOR® AND TARSO MEDIUS® SHOES

Tarso shoes have been in use for over twenty-five years.

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Spencer® SOLVES ANOTHER PATIENT'S TOTAL SUPPORT REQUIREMENTS

• Spencer first realigns the body — then designs a support to hold it that way.

Previous braces for this patient with scoliosis and kyphosis were cumbersome and conspicuous.

Her **Spencer** combines proper anatomical support with cosmetic acceptability.

She indicates Spencer is 100% better. She could not walk, sit or do her housework without it. It gives her better support and makes her stand taller as well as improving her figure and general well-being.

• Note unique placement of steels for maximum support and greatest tolerance.

Spencer's Individual Designing Service is available to you through Corsetieres specially trained to help you help your patients.

SPENCER®

individually designed supports for women, men and children

SPENCER, INCORPORATED
19 Ellsworth Ave., New Haven 7, Conn.
Canada: Spencer, Ltd., Rock Island, Quebec
England: Spencer, Ltd., Banbury, Oxon

☐ Send me the name of the nearest Spencer Corsetiere.

☐ I would like an office demonstration of Spencer benefits and features.

Name _____

Address _____

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12-59

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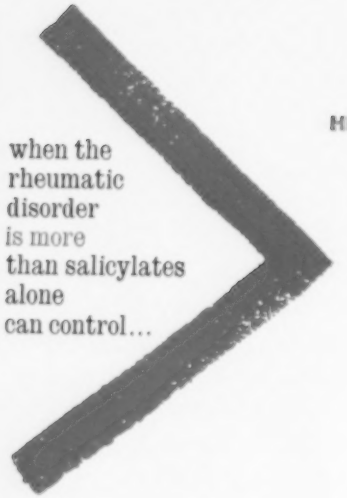
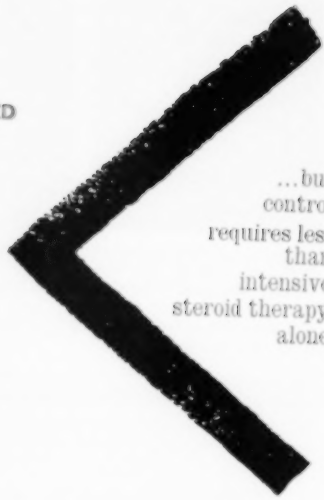


when the
rheumatic
disorder
is more
than salicylates
alone
can control...

MORE
HIGHLY INDIVIDUALIZED
THERAPY
FOR THE
RHEUMATIC
"IN-BETWEEN"



...but
control
requires less
than
intensive
steroid therapy
alone

Aristo

wider latitude in adjusting dosage

ARISTOGESIC is particularly effective for relief of chronic – but less severe – pain of rheumatic origin. ARISTOGESIC combines the anti-inflammatory effects of ARISTOCORT® Triamcinolone with the analgesic action of salicylamide, a highly potent salicylate. Dosage requirements for ARISTOGESIC are substantially lower than generally required for each agent alone. The exceptionally wide latitude of dosage adjustment with ARISTOGESIC permits well-tolerated therapy for long periods of time with fewer side effects.

Indications: Mild cases of rheumatoid arthritis, tenosynovitis, synovitis, bursitis, mild spondylitis, myositis, fibrositis, neuritis, and certain muscular strains.

Dosage: Average initial dosage: 2 capsules 3 or 4 times daily. Maintenance dosage to be adjusted according to response.

Precautions: All precautions and contraindications traditional to corticosteroid therapy should be observed. The amount of drug used should be carefully adjusted to the lowest dosage which will suppress symptoms. Discontinuance of therapy must be carried out gradually after patients have been on steroids for prolonged periods.

Each ARISTOGESIC Capsule contains:

ARISTOCORT® Triamcinolone	0.5 mg.
Salicylamide	325 mg.
Dried Aluminum Hydroxide Gel	75 mg.
Ascorbic Acid	20 mg.

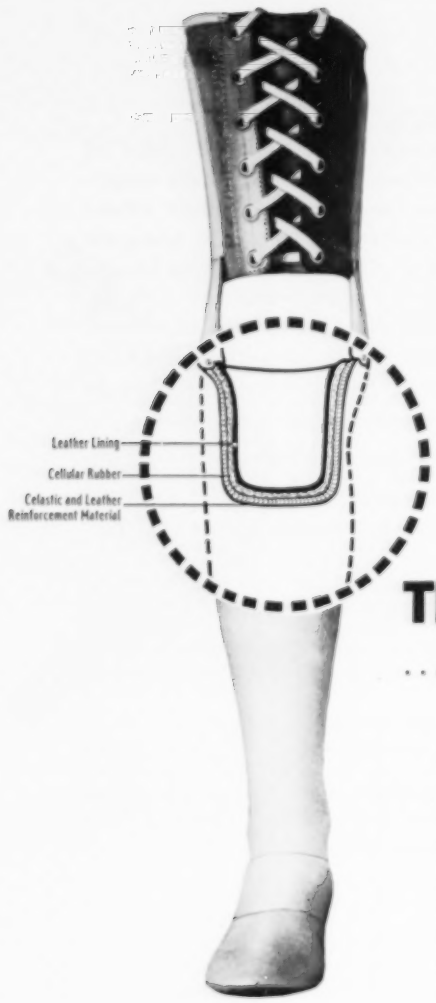
Supply: Bottles of 100 and 1,000.

gesic® Capsules

Steroid-Analgesic Compound LEDERLE

Lederle

LEDERLE LABORATORIES, A Division of AMERICAN CYANAMID COMPANY, Pearl River, New York



The Soft Socket for below-knee amputations provides a new solution for sensitive stumps where weight-bearing has been or may be uncomfortable.

In constructing the Soft Socket Limb, a special socket is made which incorporates a layer of a new nitrogen-filled cellular rubber. This produces a slight but tangible degree of softness and resiliency in the socket, with the result that the sudden pressure on the stump caused by the first impact of weight-bearing is greatly reduced. The special characteristics of cellular rubber prevent "packing", even after long periods of use, ensuring that the socket of the prosthesis will retain its original shape.

The SOFT SOCKET

. . . a new solution for sensitive stumps

Over the years, Hanger has developed, perfected and introduced outstanding achievements in artificial limbs and has cooperated closely with the program of prosthetic research sponsored by the National Academy of Sciences — National Research Council. Hanger continues Research by testing new ideas, methods and materials in constantly seeking the better way to make even better-prostheses that will bring greater happiness to amputees.

Hanger PROSTHETIC

AVAILABLE AT AUTHORIZED FACILITIES IN THE FOLLOWING CITIES:

EASTERN REGION:

BALTIMORE 1, MD.
BOSTON 15, MASS.
CHARLESTON 2, W. VA.
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RICHMOND 19, VA.
ROANOKE 12, VA.
WASHINGTON 13, D. C.

SOUTHEASTERN REGION:

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BIRMINGHAM 1, ALA.
COLUMBIA 5, S. C.
JACKSONVILLE, FLA.
MIAMI 37, FLA.
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MONTGOMERY, ALA.
NASHVILLE 5, TENN.
NEW ORLEANS 19, LA.
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CINCINNATI 29, OHIO
DALLAS 1, TEXAS
EVANSVILLE, IND.
FORT WAYNE, IND.
HOUSTON, TEXAS
INDIANAPOLIS 2, IND.
OKLAHOMA CITY 3, OKLA.
PEORIA 4, ILL.
ST. LOUIS 66, MO.
WICHITA, KANS.

In answering advertisements, please mention *The Journal of Bone and Joint Surgery*

If you or any of your patients
are bothered by backache . . .
read this report from 548 physicians about
Simmons new orthopedic-type mattress

BACK CARE

with Built-in Bedboard.

Simmons Company recently completed an extensive survey of physicians who are using the Back Care mattress. Its purpose: to obtain professional opinion of this new orthopedic-type mattress—BACK CARE® with Built-in Bedboard.

More than 500 doctors have submitted their personal appraisal of Back Care. All of them had used this new mattress to relieve chronic backache and other disorders affecting the back from which they, themselves, or some member of their families suffered.

Approximately 75 percent of the physicians rated Back Care as an "excellent" adjunct to the management of low-back pain. And the great majority of the doctors preferred Back Care to so-called "posture" mattresses or ordinary mattresses with bedboards.

Here are some typical comments received from physicians who have used Back Care:

"I am of the opinion that Back Care will meet all of the requirements of the low-back syndrome."

"I am well pleased with Back Care. I used an ordinary mattress with a bedboard underneath for 5 years. There is no comparison."

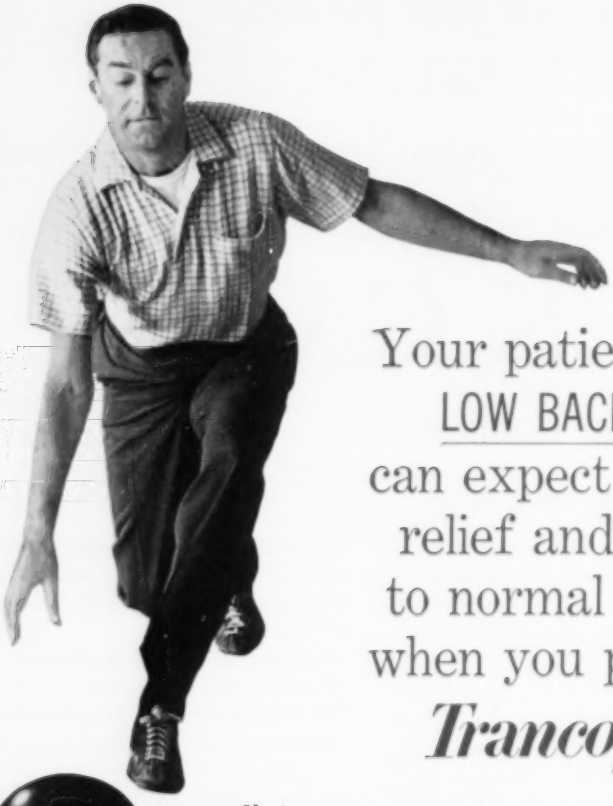
"Wholly satisfied. Would recommend Back Care to all people whether there is a back disorder or not."

"Simmons Company has rendered a very helpful aid to physicians generally and to orthopedists in particular in developing Back Care."

Doctor, we believe that you, too, will share the enthusiasm expressed by so many of your colleagues for Back Care with Built-in Bedboard. If you're looking for an entirely new type of orthopedic mattress—one that combines the desired degree of firmness and comfort—Back Care merits your consideration.

Write to Simmons Co., Dept. BB, Merchandise Mart, Chicago 54, Illinois, for a free copy of the descriptive Back Care booklet.

PAT. PENDING © 1959 SIMMONS CO., MDSE. MART, CHICAGO, ILL.



Your patients with
LOW BACK PAIN
can expect striking
relief and return
to normal activity
when you prescribe
Trancopal

case profile.[1] A 42-year-old truck driver and mover injured his back while moving a piano. The pain radiated from the sacral region down to the region of the Achilles tendon on the right side. X-rays for ruptured disc revealed nothing pertinent. The day of the injury he was given Trancopal immediately after the physical examination. Although 100 to 200 mg. three times a day were prescribed, the patient on his own responsibility increased the dosage of Trancopal to 400 mg. three times a day. This dosage was continued for three days and then gradually reduced over a ten day period. During this time, the patient continued to drive his truck. The muscle spasm was completely controlled and no apparent side effects were noted. For the past six months, the patient has continued to take Trancopal 100 to 200 mg. as needed for muscle spasm, particularly during strenuous days.

Indications—*Musculoskeletal:* Neck pain (torticollis) / Ankle sprain, tennis elbow / Bursitis / Rheumatoid arthritis / Low back pain (lumbago, etc.) / Fibrositis / Myositis / Osteoarthritis / Postoperative muscle spasm / Disc syndrome. *Psychogenic:* Dysmenorrhea / Anxiety and tension states / Asthma / Premenstrual tension / Angina pectoris / Alcoholism.

Now available in two strengths: Trancopal Caplets®, 100 mg. (peach colored, scored), bottles of 100. **New strength**—Trancopal Caplets, 200 mg. (green colored, scored), bottles of 100. **Dosage:** Adults, 100 or 200 mg. orally three or four times daily. Relief of symptoms occurs in from fifteen to thirty minutes and lasts from four to six hours.

THE FIRST TRUE "TRANQUILAXANT"
Trancopal®

Winthrop LABORATORIES • NEW YORK 18, N.Y.

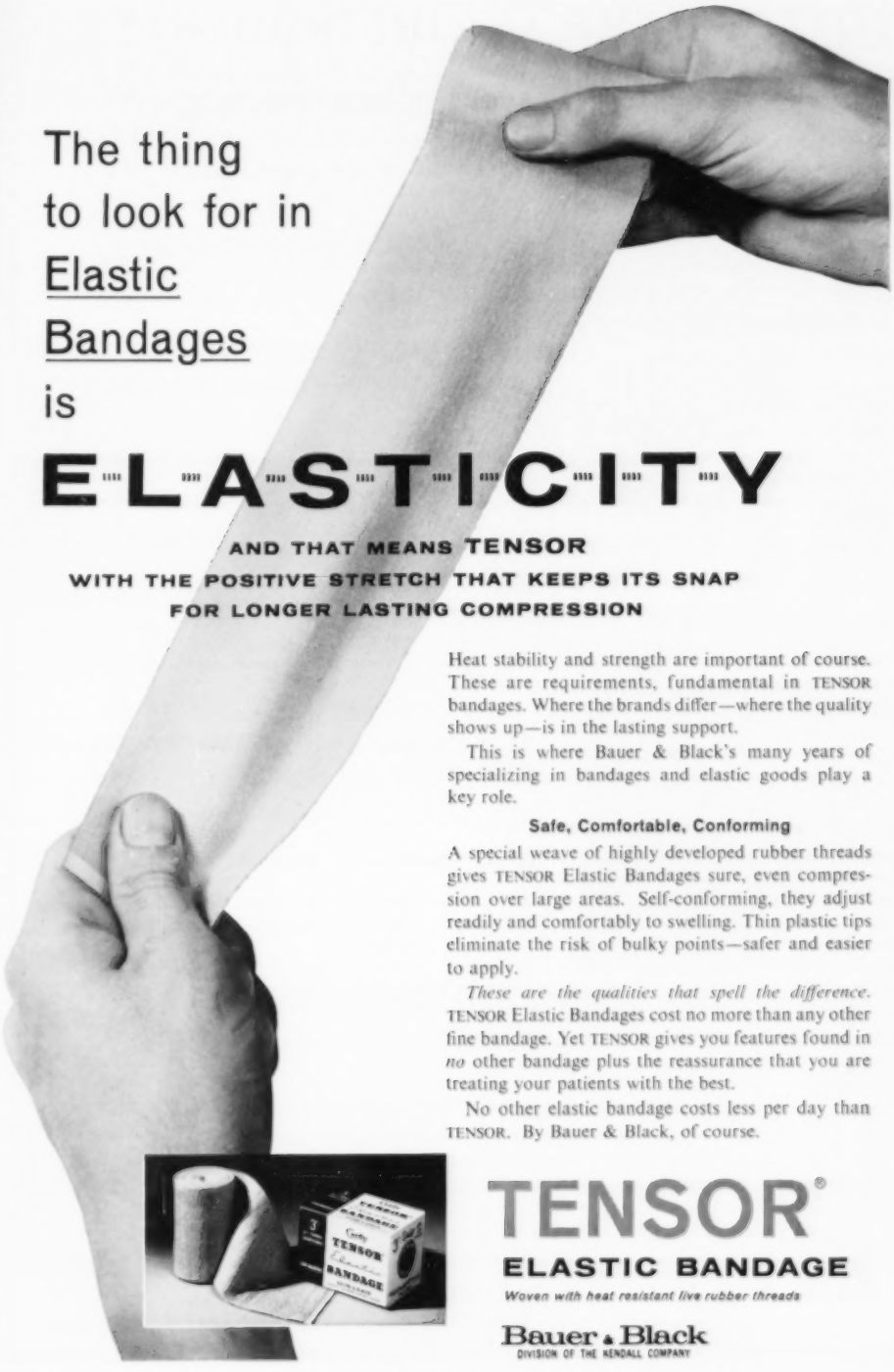
1. Collective Study, Department of Medical Research, Winthrop Laboratories.

Trancopal (brand of chlormezanone) and Caplets, trademarks reg. U.S. Pat. Off. 1416M

The thing to look for in Elastic Bandages is

ELASTICITY

AND THAT MEANS TENSOR
WITH THE POSITIVE STRETCH THAT KEEPS ITS SNAP
FOR LONGER LASTING COMPRESSION



Heat stability and strength are important of course. These are requirements, fundamental in TENSOR bandages. Where the brands differ—where the quality shows up—is in the lasting support.

This is where Bauer & Black's many years of specializing in bandages and elastic goods play a key role.

Safe, Comfortable, Conforming

A special weave of highly developed rubber threads gives TENSOR Elastic Bandages sure, even compression over large areas. Self-conforming, they adjust readily and comfortably to swelling. Thin plastic tips eliminate the risk of bulky points—safer and easier to apply.

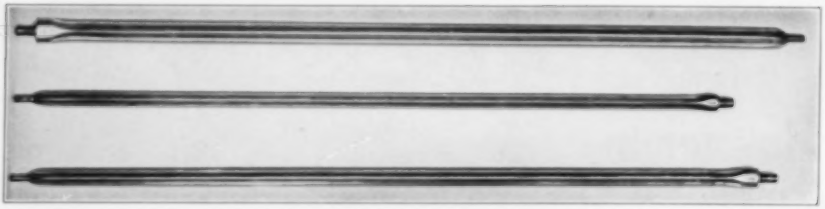
These are the qualities that spell the difference. TENSOR Elastic Bandages cost no more than any other fine bandage. Yet TENSOR gives you features found in *no* other bandage plus the reassurance that you are treating your patients with the best.

No other elastic bandage costs less per day than TENSOR. By Bauer & Black, of course.

TENSOR®
ELASTIC BANDAGE
Woven with heat resistant live rubber threads

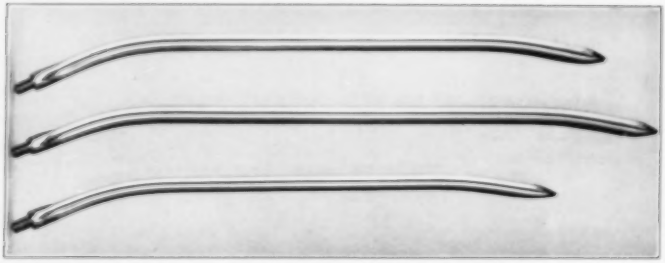
Bauer & Black
DIVISION OF THE KENDALL COMPANY

LOTTES NAILS and INSTRUMENTS

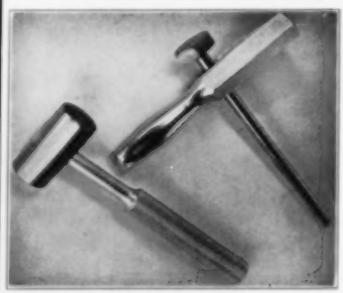


***LOTTES* FEMORAL NAILS** are manufactured with diameters of 3/8, 7/16, and 1/2 inches —with lengths in 1/2 inch variations from 14 to 20 inches.

***LOTTES* TIBIAL NAILS** are made in 5/16 and 3/8 inch diameters—in lengths from 9 to 15 1/2 inches, in variation of 1/2 inch.



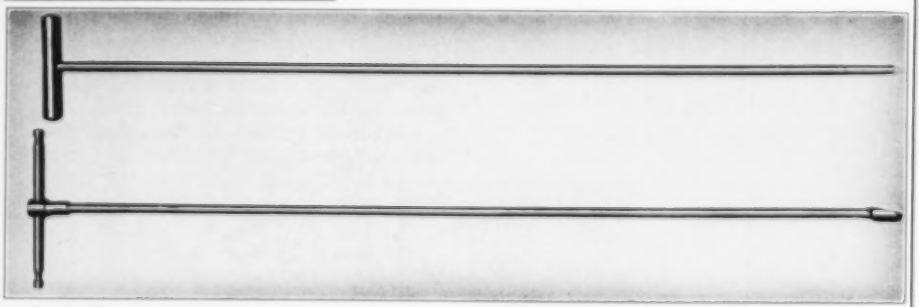
***LOTTES* NAILS AND INSTRUMENTS ARE MADE OF 18-8 SMo STAINLESS STEEL**



***LOTTES* DRIVER-EXTRACTOR COMBINATION and *LOTTES* MALLET**

***LOTTES* GUIDE WIRE AND *LOTTES* REAMER**

The reamer comes in 3 diameters: 3/8, 7/16, and 1/2 inch—all are 23 inches in length.



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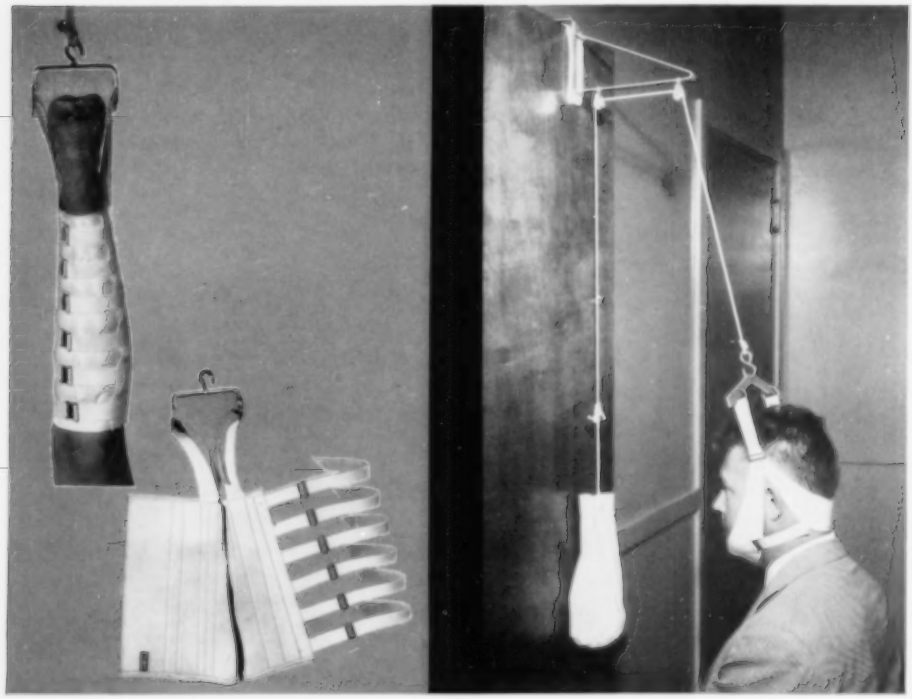

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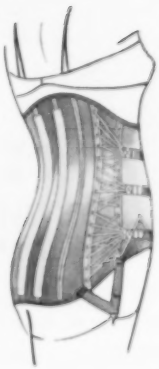

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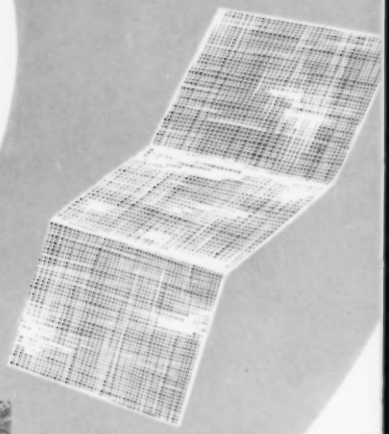

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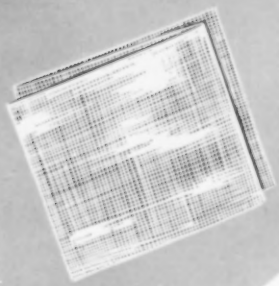

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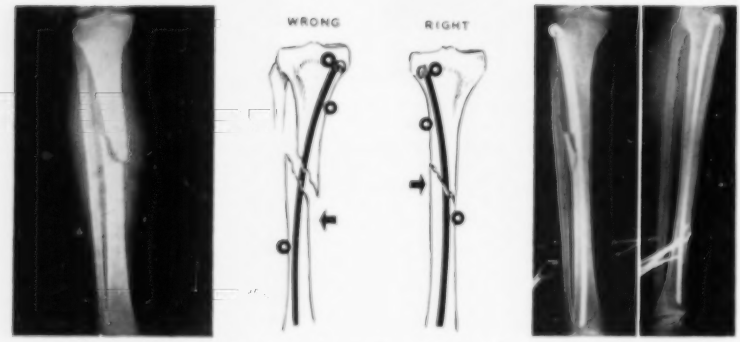
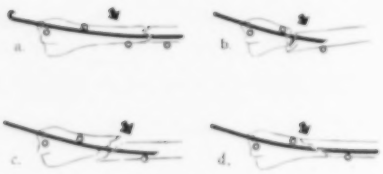


Direction of pin insertion determines compression or distraction.



V (victory) = Good Compression

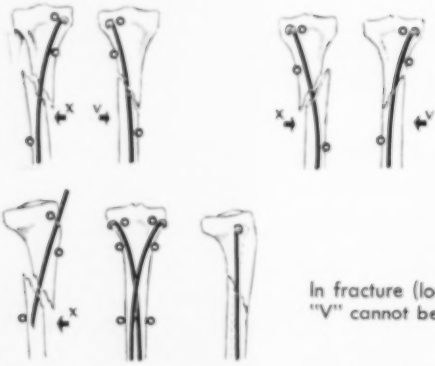
X (no good) = Distraction

RADIUS

Length of fragment and direction of fracture line determine angle of pin insertion.

RULE

Axis of pin should be same direction as axis of fracture line, intersecting to make a "V" instead of an "X".



TIBIA

In fracture (lower left), double pins required because "V" cannot be accomplished.

* Rush, Leslie V.; Fracture Problems, Mississippi Doctor, Vol. 36, No. 10, March 1959.

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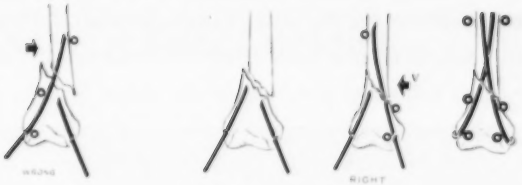


LOWER FEMUR

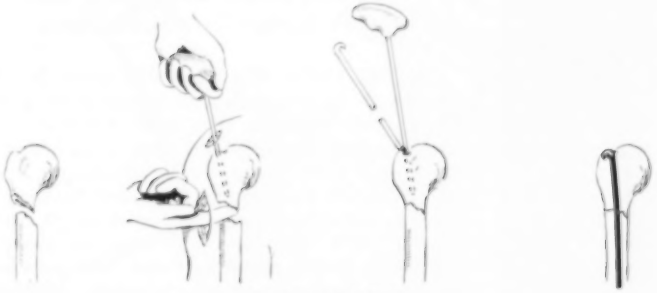
Double pins required. Introduce most effective pin first.

UPPER FEMUR

Dependent upon direction of fracture line, special type pin might be indicated.

HUMERUS, BELOW DELTOID

Requires precise handling for good healing. For fracture at right use large curved pin for compression.



UPPER THIRD

To avoid angulation, insert pin axially in short fragment.

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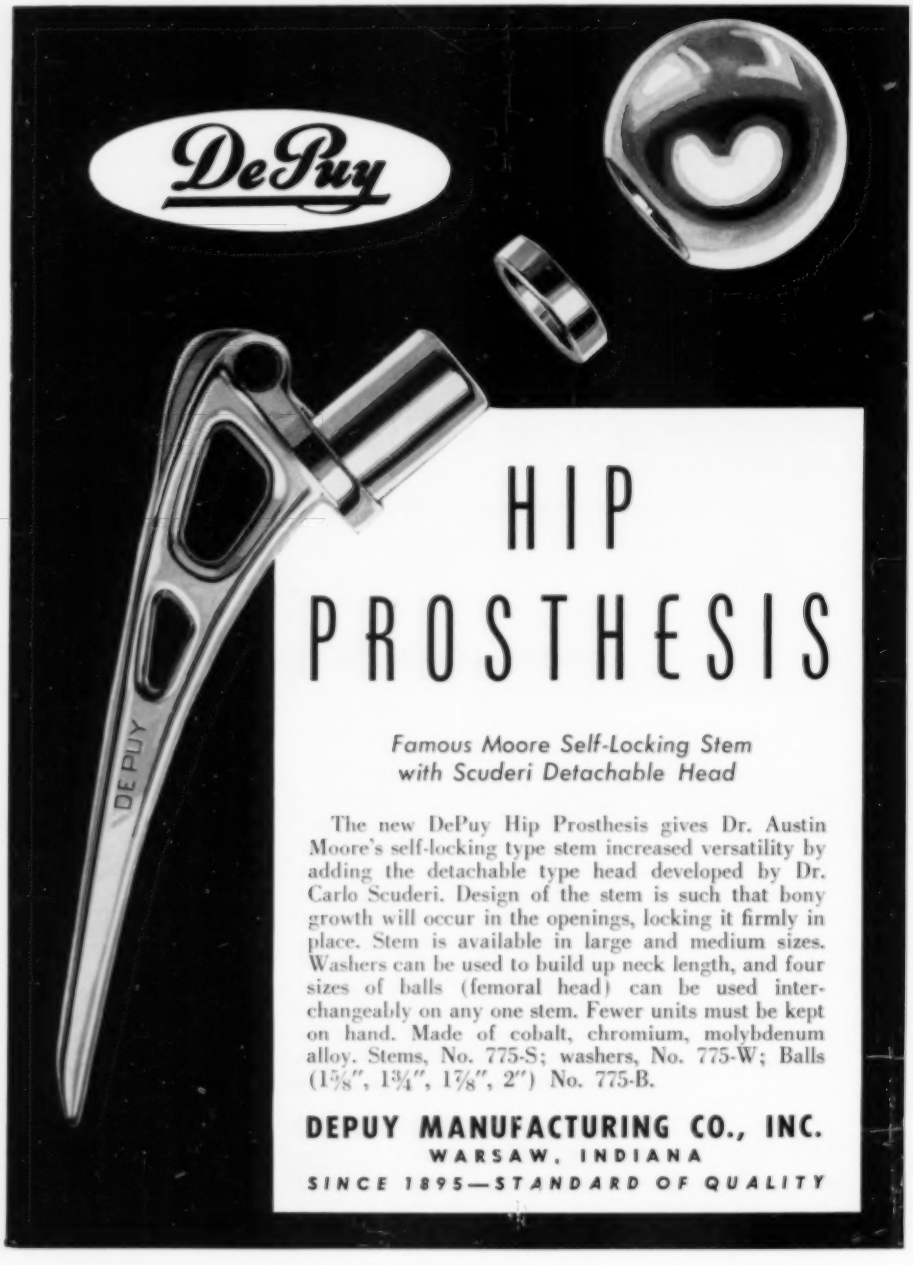
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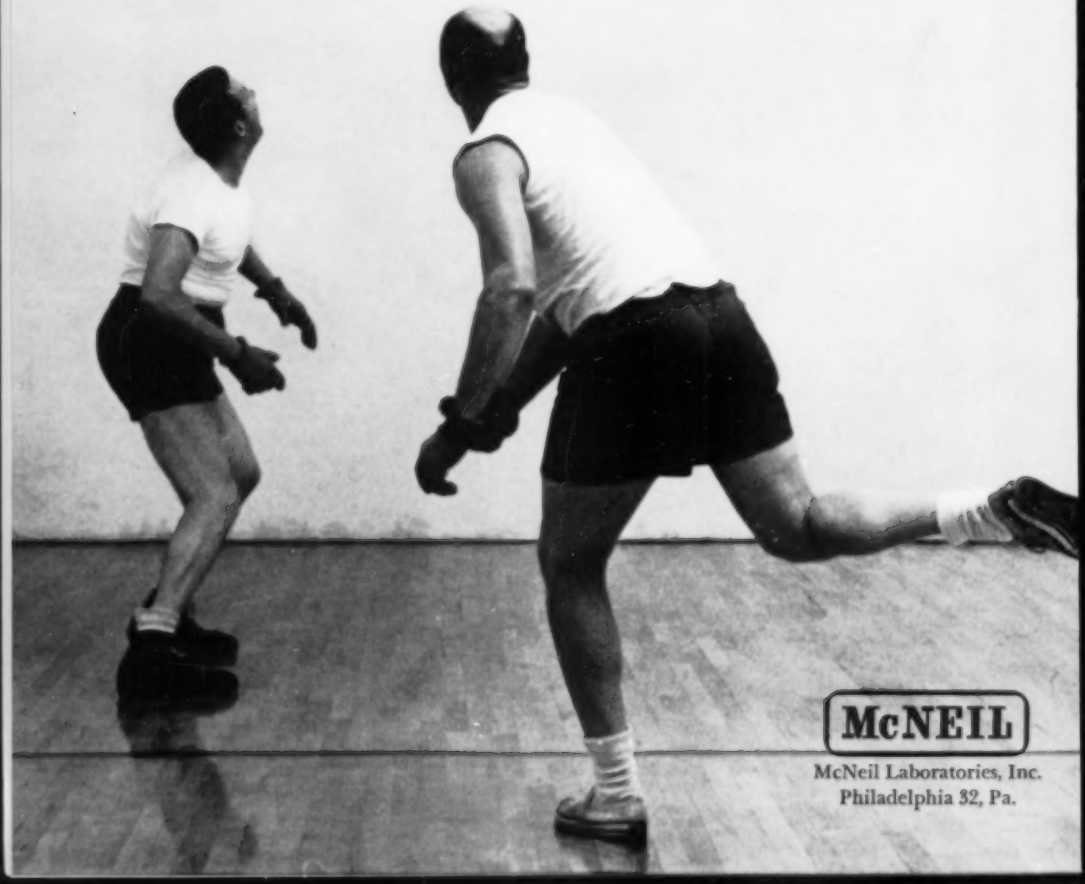
*U.S. Patent Pending



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VOLUME 41-A, NO. 8 DECEMBER 1959

The Journal of
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Fragmentation, Realignment, and Intramedullary Rod Fixation of Deformities of the Long Bones in Children

A Ten-Year Appraisal*

BY HAROLD A. SOFIELD, M.D., AND EDWARD A. MILLAR, M.D.,
CHICAGO, ILLINOIS

From the Shriners' Hospitals for Crippled Children, Chicago

The procedure of fragmentation, realignment, and fixation with an intramedullary rod, employed at the Chicago Unit of Shriners' Hospitals for the deformities of osteogenesis imperfecta, was exhibited in 1951, in Chicago, at the Annual Meeting of The American Academy of Orthopaedic Surgeons. A paper on the subject was given before The Academy one year later. The procedure has found wide acceptance in the treatment of osteogenesis imperfecta and appears to have withstood the test of time. Modifications of the same procedure have also been used in the treatment of congenital pseudarthrosis of the tibia and of other conditions where realignment and stabilization of long bones is desirable. It is our intent, in this paper, to evaluate the results of this procedure after a reasonably long follow-up in a considerable number of cases of osteogenesis imperfecta, and to report our experience with the procedure in other diseases.

Since 1948 the operation of fragmentation, realignment, and stabilization with an intramedullary rod has been employed 117 times on the long bones of fifty-two children with the following conditions: osteogenesis imperfecta, congenital pseudarthrosis of the tibia, rachitic deformities, fibrous dysplasia of bone, and congenital shortening of the femur and tibia.

TECHNIQUE

The surgical technique (Figs. 1-A through 1-D) consists in subperiosteal exposure of the entire shaft of the bone, osteotomy through the proximal and distal metaphyses, and removal of the shaft from its bed. The bone is then studied to ascertain how many additional fragments need to be made in order to thread the pieces on a straight, round steel rod. If the bone is very crooked, it may be necessary to cut the shaft into three or four pieces; if the shaft is only moderately bowed, two pieces may suffice. An effort is made to keep the fragments to the smallest practical number. The fragments are then threaded on a rod appropriate in diameter to the size of the intramedullary canal (Fig.

*Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 25, 1959.

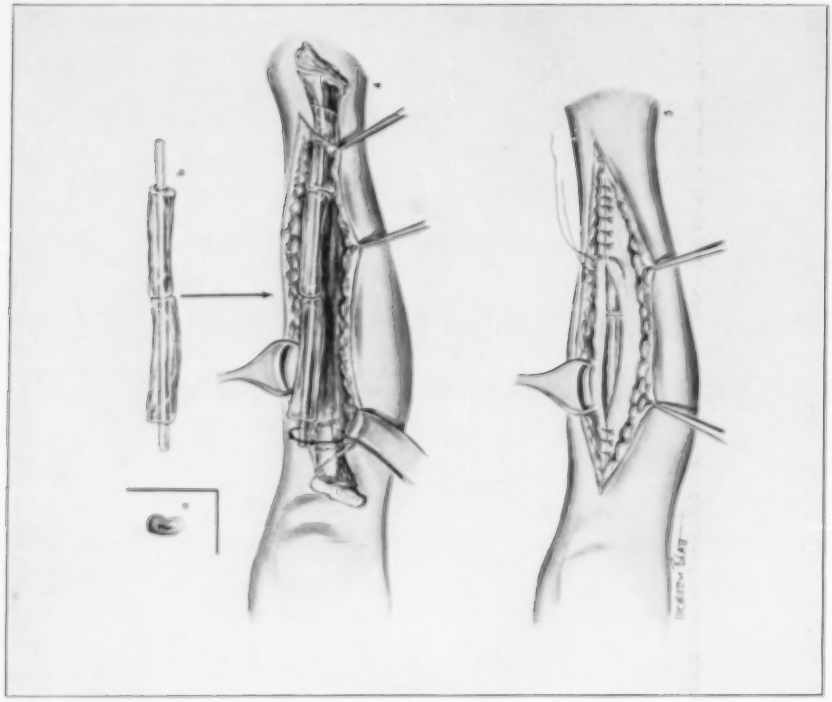

Fig. 1-B

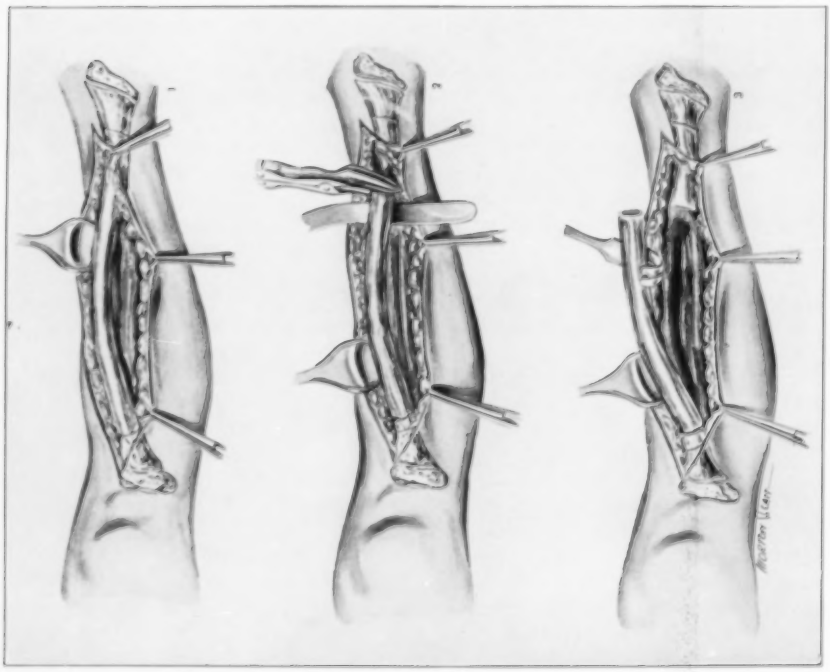

Fig. 1-A

Figs. 1-A and 1-B: Tibia. Technique for fragmentation, realignment, and insertion of an intramedullary rod. Note, in Fig. 1-B, the distorted cross-sectional anatomy (*a*); the manner in which the fragments are threaded on the rod (*b*); and the procedure for manipulating the proximal end of the rod into the slot in the posterior cortex of the proximal metaphysis (*c*). The distorted cross-sectional anatomy may complicate the insertion of the rod.

1-B). No effort is made to replace the fragments in their original positions in relation to the other fragments. The pieces are threaded on the rods in the manner that seems to bring them into the straightest possible line. Some fragments may be turned end for end and others rotated 180 degrees around the long axis. Similarly, fragments originally in a proximal position in the shaft may be placed distally. When the shaft is realigned on the rod it resembles a shish kebab. The rods are provided with tapered ends to facilitate passage through the medullary canal of the bone. If the rod is passed retrograde in the femur, or the ulna, or the humerus, one end is cut off to proper length and the projecting portion bent beyond a right angle to prevent the rod from backing out through the soft tissues. The rods commonly used are the

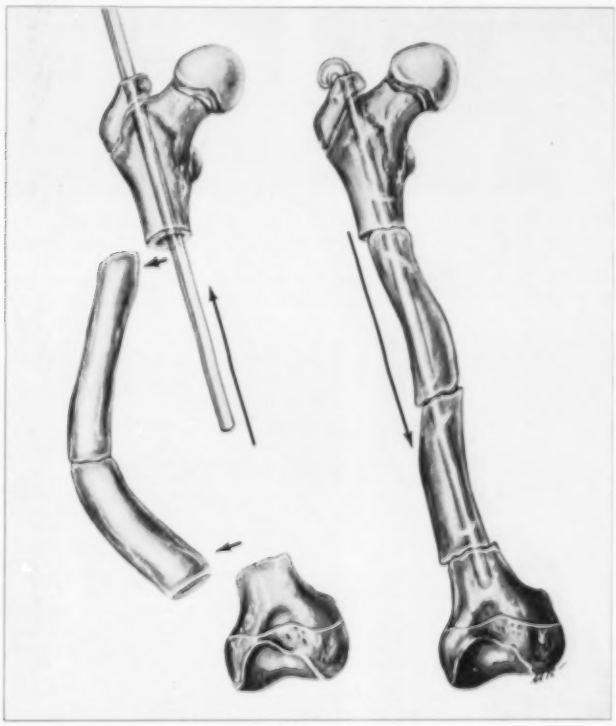

FIG. 1-C

Femur. Technique for realignment of fragments and retrograde insertion of the intramedullary rod. After insertion into the distal fragment the proximal end of the rod is cut off and bent to form a hook to discourage migration of the rod.

standard stainless-steel pins ranging from five-sixty-fourths to one-quarter of an inch in diameter. It is not practical to stock rods that are graduated in length; therefore, rods of the maximum available length are obtained from the surgical supply house. At the operating table the rod is cut to proper length with a double-action bolt cutter. The projecting end of the rod is bent or curled by pliers. Should the size of the bone demand a larger rod, either the Rush or Küntscher rod may be used. If the bone is very crooked, some of it may have to be discarded before being placed on the rod in a straight line because it may be too long to force into the gap between the metaphyses. When the straightened shaft is replaced, the distal end of the rod extends to the vicinity of the distal epiphyseal line, and the proximal end lies either in

FIG. 2-A

FIG. 2-B

Figs. 2-A through 2-D: M.C. Osteogenesis imperfecta: deformity and fracture of the left femur.

Fig. 2-A: October 18, 1940. Healing fracture, as shown when the patient was four years old.

Fig. 2-B: October 20, 1948. Refracture, as shown when the patient was twelve years old.

FIG. 2-C

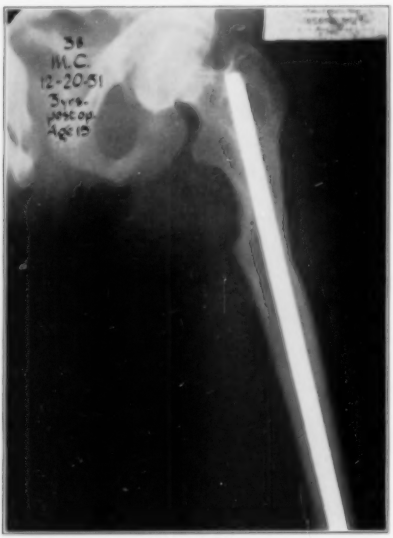

FIG. 2-D

Fig. 2-C: November 22, 1948, three weeks after realignment and insertion of an intramedullary rod. (The rod was too long, but was subsequently shortened.)

Fig. 2-D: December 20, 1951, three years after operation, when the patient was fifteen years old. The roentgenogram showed that the fracture had healed and that alignment had been maintained.

the medullary canal close to the proximal epiphyseal line as in the case of the tibia or projects just above the proximal end of the bone as in the case of the femur, the ulna, and the humerus, where the rod is inserted in a retrograde manner.

Deformities of the tibia (Figs. 1-A and 1-B) were treated most frequently by this method. A slot, approximately one inch in length and the width of the rod, is made with a curette in the posterior cortex of the proximal metaphysis. The distal end of the rod is then manipulated over the lateral cortex of the proximal metaphysis, through the posterior slot, and into the medullary cavity of the proximal fragment. As the displacement of the rod tends to be anterior, it is secured in position by the intact anterior cortex. The fibula does not offer sufficient mechanical resistance to require attention.

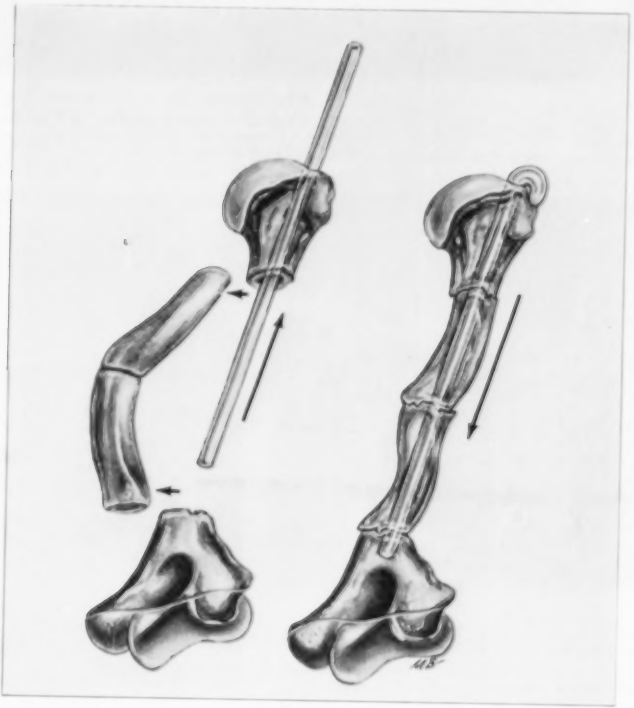

FIG. 3

Humerus. Technique for realignment and insertion of the rod in a retrograde fashion.

In the femur (Fig. 1-C) the proximal end of the rod is driven retrograde up the medullary canal to emerge just medial to the greater trochanter and, then after the fragments of the shaft are threaded on the rod, the distal end is driven into the distal metaphysis (Figs. 2-A through 2-D).

A deformity of the humerus (Fig. 3) is treated in a similar fashion. The rod is initially driven in a retrograde direction through the proximal metaphysis coming out at the lateral margin of the epiphysis. It is then gradually driven distally, and the fragments are threaded on to it until its distal end is seated in the distal metaphyseal fragment (Figs. 4-A, 4-B, and 4-C).

Fixation of the ulna after fragmentation and realignment of the shaft is accomplished by the conventional method used in fractures: the rod is driven either retrograde or directly through the olecranon. It is usually necessary either to fracture manually or to osteotomize the radius when this is done, but the ulna and the radius are not fixed at the same operation. The radius rarely requires fixation.

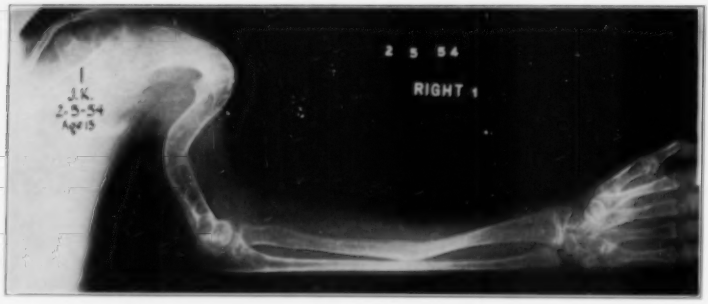

FIG. 4-A

Figs. 4-A through 4-C: J.K. Osteogenesis imperfecta: humerus and ulna.
Fig. 4-A: February 5, 1954. Deformity, as shown on preoperative roentgenograms made when the patient was thirteen years old.

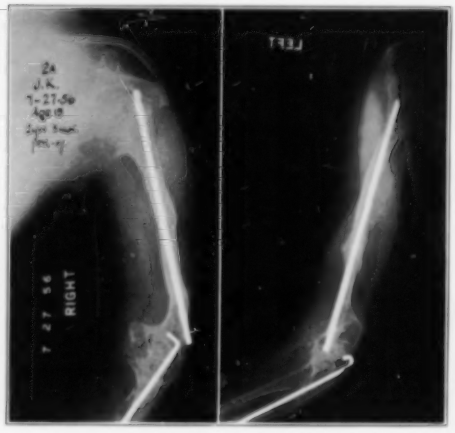

FIG. 4-B

Fig. 4-B: August 27, 1956. The humerus two years and three months after operation.
Fig. 4-C: August 27, 1956. The ulna one year and nine months after operation.

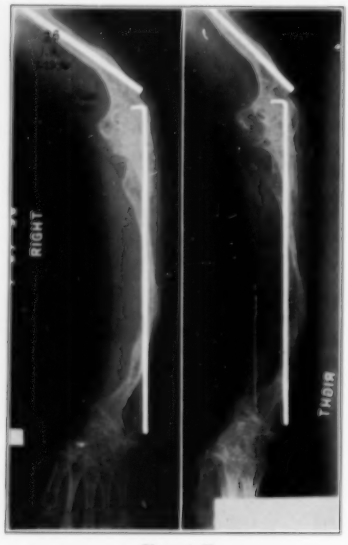

FIG. 4-C

Once the rod and attached fragments are in position, the periosteum is closed as much as possible. The remaining soft tissues are then sutured over the bone, and the extremity is immobilized in a plaster cast. Tourniquets are employed, if at all possible, but they can seldom be used in patients with severe osteogenesis imperfecta. Blood transfusions are given almost routinely during surgery.

COMPLICATIONS

This procedure with its extensive exposure and removal of practically the entire shaft of a long bone seems somewhat radical on first observation. It would appear to offer ample opportunity for complications, but there have been surprisingly few major complications.

Two deaths occurred, one of which was not due to the surgical procedure *per se;* it was the result of a respiratory obstruction caused by aspiration. This patient had tolerated eight previous similar procedures without difficulty. The second death occurred in a child suffering from osteogenesis imperfecta in whom hypotension developed three hours after fragmentation and fixation of

the tibia. The exact cause of the death is not known as permission for an autopsy was not granted. This patient had also undergone six previous operations without difficulty.

There were two serious infections. One was a primary infection due to *Staphylococcus aureus*. The wound eventually closed after an involucrum had developed of sufficient size to provide continuity of the bone and permit the removal of sequestrum. The other infection developed after the insertion of an autogenous-bone graft. Although there is still occasional drainage from this leg two years after operation, bone continuity has been established.

Non-union did not occur, and no major vascular embarrassment developed in any of the patients.

The only nerve injury was severance of the radial nerve in a patient, five and one-half years old, with osteogenesis imperfecta mid-way between the shoulder and elbow. This injury can easily happen in view of the distorted anatomy. Primary repair led to return of function of the extensors of the wrist in seven weeks, of the extensors of the fingers in eight weeks, of the extensors and abductor of the thumb in nine and one-half weeks, and complete sensory return in sixteen weeks. The reason for the unusually rapid return is not understood. Minor mechanical complications also occurred, which can be attributed to errors in judgment.

ENTITIES TREATED

Osteogenesis Imperfecta

The procedure was performed most often in cases of osteogenesis imperfecta; there were eighty operations on twenty-two patients. The youngest patient was six weeks old at the time of the initial surgery; the oldest was thirteen years. The majority were between two and eight years of age at the time of initial operation. The surgeon cannot select a preferred age, since the need for surgery is dictated by the severity of the disease. Eleven patients had four or more, and two had eight major long bones treated by this procedure. Initially, surgery was not performed until a fracture occurred. As experience was gained, it was considered justified to perform the procedure for marked deformity as an elective or prophylactic measure (Figs. 5-A through 6-E).

Although the deformities of the longitudinal configuration of these afflicted bones are easily visualized clinically and roentgenographically, it is not until one has exposed a few of these bones at operation that the marked distortion of the cross-sectional anatomy of these bones is recognized. This distortion may frequently lead to difficulty when one attempts to pass a rod through the canal; occasionally, a fragment may be split longitudinally. This further fragmentation was worrisome earlier in the work, but it was soon found that when it occurred the pieces needed only to be placed around the rod in a barrel-stave fashion. Solid bone union occurred in every instance with a medullary canal forming around the rod (Figs. 7-A and 7-B).

In two patients in whom the tibiae were extremely thin, the entire shafts were replaced by homogenous-fibula grafts taken from relatives (Figs. 8-A through 8-G). It was of interest to note that in time the graft was completely replaced by imperfect bone. Bone-bank or homogenous grafts are frequently employed, particularly in cases of osteogenesis imperfecta, when available autogenous bone is of poor quality.

From time to time the epiphyseal plate was invaded by the rod, but no disturbance in epiphyseal growth was noted in the patients followed to date.

With growth the bone extends beyond the rod almost invariably at the distal end. When this occurs the bone may either bend, causing the end of the rod to protrude through the anterior cortex, or the bone may fracture distal to the rod (Figs. 9-A and 9-B). It is then necessary to introduce a longer rod, performing an osteotomy of the distal portion of the bone if it requires realign-

FIG. 5-A

FIG. 5-B

Figs. 5-A through 5-F: B.P. Osteogenesis imperfecta: severe involvement.
Fig. 5-A: September 11, 1945. Roentgenogram made when the patient was three years old shows bilateral femoral deformities.
Fig. 5-B: March 17, 1950. Fracture of the right femur.

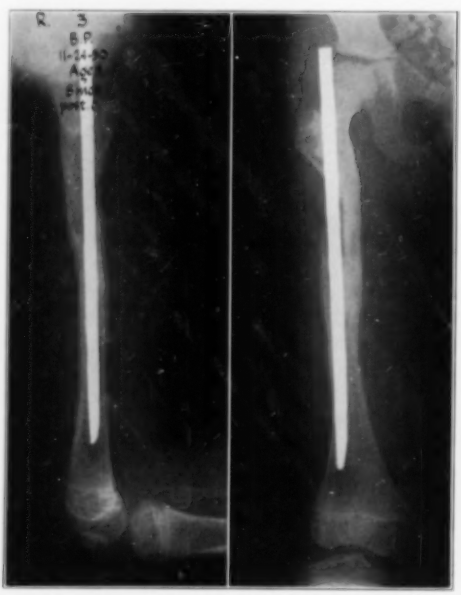

FIG. 5-C

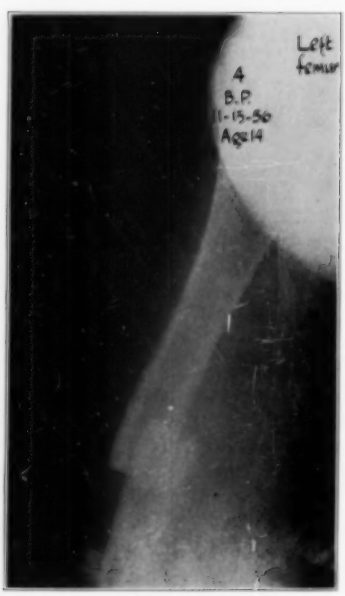

FIG. 5-D

Fig. 5-C: November 24, 1950. The right femur eight months after operation.
Fig. 5-D: November 13, 1956. Fracture of the left femur.

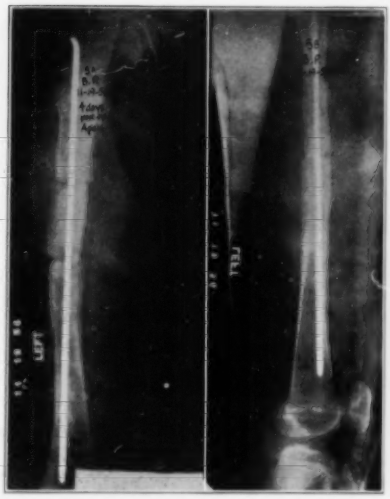

FIG. 5-E

FIG. 5-F

Fig. 5-E: November 19, 1956. The left femur four days after operation.
Fig. 5-F: September 27, 1957. The left femur ten months after operation; the right femur seven years after operation.

ment. The average time for overgrowth to occur was two and one-half years. The fact that overgrowth almost invariably is at the distal ends of the long bones raises some doubts concerning the accuracy of present concepts of the percentage of bone growth of individual epiphyses.

The ultimate control of all the problems of osteogenesis imperfecta will be found in the realm of bone physiology, but until adequate knowledge becomes available, it is felt that fragmentation, realignment, and intramedullary fixation offer definite advantages over methods previously employed. These advantages are: (1) the frequency of fractures is reduced and pain diminished; (2) deformities are corrected and frequently prevented before they occur; and (3) the child can use his limbs in a more normal fashion because they are less painful and more stable.

Congenital Pseudarthrosis

Perhaps the most interesting group of patients in this series, except those with osteogenesis imperfecta, are the five children with congenital pseudarthrosis. Although this is a small number of cases, the results have been encouraging.

Three patients, aged two, seven, and nine years, respectively, with typical congenital pseudarthrosis of the tibia were treated by fragmentation of the shaft and intramedullary fixation. All three obtained solid union and have maintained it for six, five, and four years, respectively, since their first operations. The technique, which varied from that used in other conditions (Fig. 10), was essentially the same in all three cases. Here the arrangement of the fragments does not permit the same random placement. The shaft of the tibia is cut through at both metaphyseal areas and, since it is ununited, can be removed from the extremity in two pieces. If the distal piece is short and atrophic, it is discarded; if it is of useful length and composed of solid bone, it is retained. The thin, pointed ends of both fragments at the area of pseudarthrosis are trimmed off and discarded. The upper fragment with its base or large end at the osteotomy site just below the knee is reversed end for end and its base placed against the osteotomy site just above the ankle. The thick proximal

FIG. 6-A

FIG. 6-B

Figs. 6-A through 6-E: B.P. (Same patient as seen in Figs. 5-A through 5-F.)

Fig. 6-A: April 6, 1949. Preoperative roentgenogram, made when the patient was six and one-half years old, shows a fracture of the right tibia.

Fig. 6-B: November 24, 1950. The right tibia one year after plating operation. (Plates that are bent to conform to the shape of the bone are no longer used.)

FIG. 6-C

FIG. 6-D

FIG. 6-E

Fig. 6-C: August 12, 1955. Right tibia one day after operation. Fragmentation, realignment, and fixation with an intramedullary rod were performed after the plate and screws were removed.

Figs. 6-D and 6-E: September 27, 1957. The right tibia two years after operation. Note the angulation of the tibia proximal to the rod. (The left tibia was not fractured and remained relatively free of deformity.)

FIG. 7-A

FIG. 7-B

Figs. 7-A and 7-B: E.K. Osteogenesis imperfecta: left humerus and ulna.
Fig. 7-A: June 25, 1951. Preoperative roentgenogram made when the patient was eight years old: note the fragility of the cortices.
Fig. 7-B: August 26, 1953. The humerus fifteen months after operation; the ulna one year after operation.

portion of this fragment now spans the area of pseudarthrosis. If the original lower fragment is fairly solid, it is placed above the transplanted upper fragment with its metaphyseal region against the upper end of the reversed large fragment. The point of the lower fragment that was originally in the pseudarth-

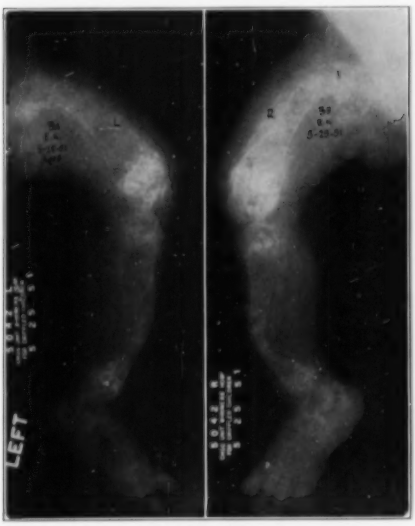

FIG. 8-A

FIG. 8-B

Figs. 8-A through 8-C: E.K. Osteogenesis imperfecta: left and right tibiae.
Fig. 8-A: May 25, 1951. Preoperative roentgenogram made when the patient was eight years old.
Fig. 8-B: June 25, 1952. The right tibia ten months after operation; the left tibia eight months after operation.

FIG. 8-C

FIG. 8-D

FIG. 8-E

Figs. 8-C and 8-D: September 19, 1956. The left tibia two months after insertion of a new rod and re-enforcement of bone with an autogenous iliac graft. The distal end of the rod was bent into a hook in an attempt to prevent penetration through the cortex. Union occurred, but cortices remained thin despite the graft.

Fig. 8-E: May 29, 1957. The left tibia two months after insertion of a homogenous fibular graft and a new rod.

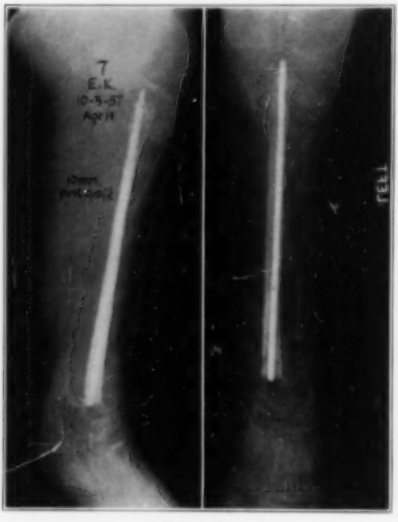

FIG. 8-F

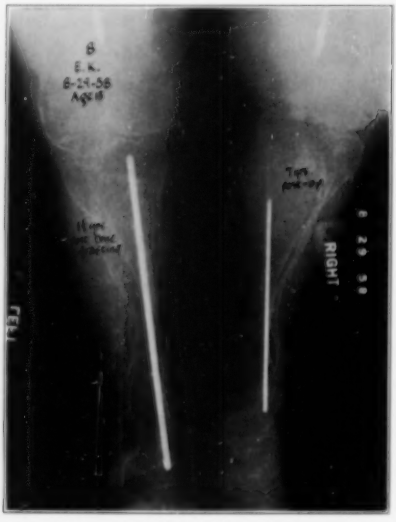

FIG. 8-G

Fig. 8-F: October 3, 1957. The left tibia ten months after operation.

Fig. 8-G: August 29, 1958. The left tibia one and one-half years after homogenous fibular grafting; the right tibia seven years after the initial procedure of fragmentation, realignment, and fixation with an intramedullary rod.

rotic region is now pushed into the metaphyseal area below the knee. Fixation of these fragments is accomplished by an intramedullary rod as described in the treatment of osteogenesis imperfecta. If the lower fragment has been discarded, a bone graft, usually from a bone bank, is placed just below the knee. In two instances a piece of bone-bank fibula has been used successfully. One patient was re-explored on two occasions because of questionable union

of the graft, but union was found to be present in each instance (Figs. 11-A through 11-E). Anterior angulation developed at the site of pseudarthrosis in another patient despite the rod, and re-exploration was performed two years after the original procedure. No lack of continuity could be demonstrated. However, osteotomy was performed, a new rod was inserted, and autogenous iliac bone was added. Although sepsis due to *Staphylococcus aureus* with drainage appeared in the operative site, the bone again proceeded to solid union. The fourth and fifth patients of this group presented pseudarthroses of the radius and the fibula respectively. In both there was an associated neurofibromatosis. Union was obtained in both by the use of intramedullary rods and autogenous

FIG. 9-A

FIG. 9-B

Figs. 9-A and 9-B: Osteogenesis imperfecta: complications caused by growth.

Fig. 9-A: September 12, 1955. Roentgenogram of the right tibia, made two years after operation when the patient was fourteen years old. There is overgrowth with recurrence of bowing and penetration of the rod through the cortex.

Fig. 9-B: March 10, 1954. The left femur two years after operation when the patient was thirteen years old. There is refracture at the distal end of the rod.

grafts. It should be re-emphasized that the proper appraisal of this particular method awaits the collection of additional cases. The experience of Moore and Stelling, who used this technique according to our recommendations for congenital pseudarthrosis of the tibia, suggests that union is not always obtained or maintained. Thus, time may counterbalance these initial successes with failures.

Resistant Rickets

Osteotomy for the correction of rachitic deformities of long bones has long been in vogue, but this usually has been restricted to one level of the involved

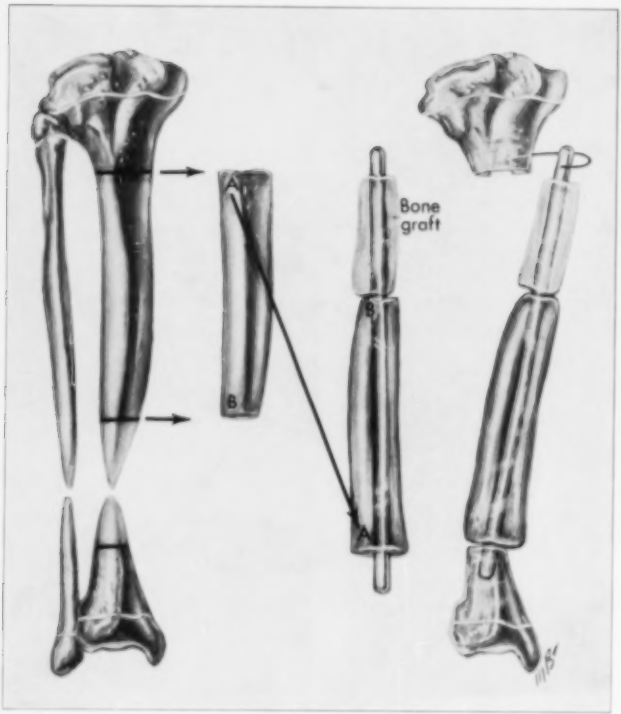

FIG. 10

Congenital pseudarthrosis. Technique for resection of pseudarthrosis, replacement of shaft fragment, placement of bone graft, and fixation with an intramedullary rod.

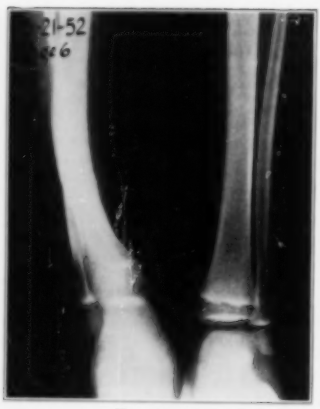

FIG. 11-A

FIG. 11-B

Figs. 11-A through 11-E: J.B. Congenital pseudarthrosis: right tibia.

Fig. 11-A: May 21, 1952. Preoperative roentgenogram of the tibia made when the patient was six years old demonstrating anterior bowing but no pseudarthrosis.

Fig. 11-B: October 6, 1953. Pseudarthrosis occurred after osteotomy in August 1952 and persisted despite bone-grafting in June 1953. Both operations were performed prior to the patient's admission to this hospital.

FIG. 11-C

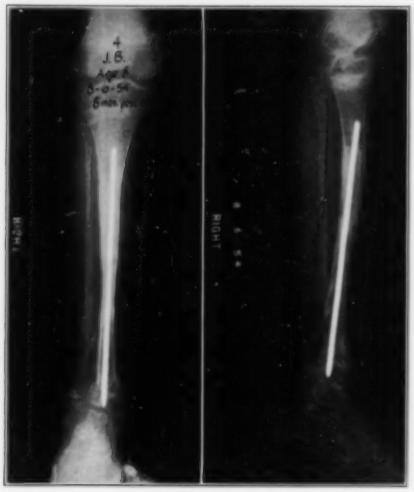

FIG. 11-D

Fig. 11-C: January 13, 1954. Two weeks after fragmentation, bone-grafting, and fixation with a rod.

Fig. 11-D: August 6, 1954. Eight months after operation; healing has occurred.

bone at any given procedure. An intramedullary rod supplies a means whereby multiple osteotomies can be performed at one procedure and the fragments maintained in alignment. This method possesses definite advantages because it gives a greater degree of correction. The procedure of primary fragmentation and fixation with an intramedullary rod was performed eleven times—nine times on femora and twice on tibiae—in six patients suffering from so-called resistant rickets. Unprotected weight-bearing was permitted in all instances three months after operation. The improvement in appearance and in function was considerable in all these patients (Figs. 12-A through 12-F).

FIG. 11-E

August 29, 1958. Four years and eight months after operation. Note the persistence of the defect in the fibula and the growth disturbance on the distal tibial epiphysis. The medullary canal has formed around the rod in the tibia.

Fibrous Dysplasia

Deformities of a lesser degree are often seen in fibrous dysplasia of the long bone. In the femur there is usually a severe varus deformity of the neck accompanied by bowing of the shaft of the femur. Osteotomy and insertion of special rods and nails were carried out in two patients (Figs. 13-A, 13-B, and 13-C). These rods were designed individually for each patient by first making a paper femur based on the roentgenographic appearance of the real femur. This pattern was then cut and the pieces arranged to produce the desired cor-

FIG. 12-A

FIG. 12-B

FIG. 12-C

Fig. 12-A: C.M. Resistant rickets with deformities of both lower extremities. Preoperative roentgenogram showing bowing of femur when patient was twelve and a half years old.

Fig. 12-B: October 22, 1956. Left femur two months after operation showing levels of osteotomies.

Fig. 12-C: September 5, 1958. Two years after operation. Note reconstitution of fragments.

rected position. The pattern was then used to determine the dimensions for the solid, stainless-steel rod, which was round in contour with the base or proximal end of an increased diameter. A threaded channel was bored through this base at such an angle that the small, solid nail which was to project into the femoral neck and head would traverse the intramedullary rod. At surgery the intramedullary rod was introduced into the proximal end of the femur in a retrograde fashion after a wedge of bone had been removed from the lateral cortex and an osteotomy performed at the level of the lesser trochanter. After the intramedullary nail was in place, the small nail was then driven into the femoral head through the channel in the rod which was visible at the junction of the fragments where the portion of the lateral cortex had been removed. The procedure is not an easy one; it is suggested that one should not select this type of case to do early in his experience.

Congenital Shortening of Bones

The postoperative follow-up of the cases of osteogenesis imperfecta suggested that stimulation of longitudinal bone growth had occurred. This observation suggested that when the diaphyseal blood supply is interrupted by the rod, the metaphyseal blood supply may be increased as a compensatory mechanism promoting epiphyseal growth activity, as has been postulated by Trueta. If this is true, it was reasoned that an increased rate of growth might be anticipated after the fragmentation procedure. Based on this premise, attempts at stimulation of bone growth were made in nine patients with congenital absence of the fibula and associated shortening of the tibia, and in four patients with congenital shortening of the femur.

FIG. 12-D

FIG. 12-E

Fig. 12-D: September 5, 1958. Two years after operation.
Fig. 12-E: October 22, 1956. Left tibia three weeks after operation showing osteotomy sites.

FIG. 12-F

September 5, 1959. Two years after operation showing reconstitution of the tibiae.

In infants with congenital absence of the fibula in whom leg-length discrepancy is not greater than two inches and in whom the distal tibial epiphysis appears to be present, enough stimulation of epiphyseal growth seems to occur to justify the procedure (Figs. 14-A, 14-B, and 14-C). One patient had a leg-length discrepancy of three-quarters of an inch that has remained the same from his fourth to ninth year; perhaps an amputation has been avoided in this instance. Two patients in whom the discrepancy was less than two inches have shown a diminution in the inequality of their leg lengths over a two-year period. Three patients in whom the discrepancy was greater than three inches have failed to gain enough length to avoid having amputation performed. Suf-

FIG. 13-A

Figs. 13-A through 13-C: B.R. Fibrous dysplasia: deformity of the right femur.
Fig. 13-A: September 24, 1952. Preoperative roentgenogram made when the patient was six years old.

FIG. 13-B

FIG. 13-C

Fig. 13-B: December 8, 1952. Two and one-half months after subtrochanteric osteotomy and fixation with a nail and an individually designed rod. The round nail is threaded near its head and screwed into the hole through the proximal end of the rod.
Fig. 13-C: September 21, 1956. Four years after operation.

FIG. 14-A

FIG. 14-B

Figs. 14-A through 14-C: S.C. Congenital absence of the fibula with shortening and bowing of the tibia.

Fig. 14-A: October 16, 1953. Preoperative roentgenogram made when the patient was three years old; the difference in leg length is 2.6 centimeters.

Fig. 14-B: October 18, 1954. Two days after operation.

Fig. 14-C: August 25, 1958. Three years and ten months after operation; the difference in leg length is 2.1 centimeters.

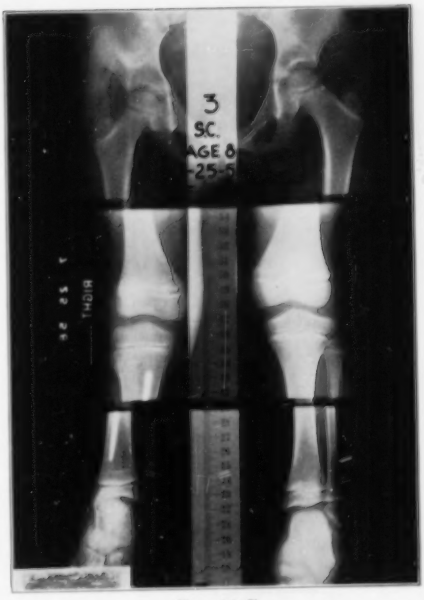

FIG. 14-C

ficient time has not elapsed to evaluate the remaining three patients.

The results obtained after osteotomy of the long bones to stimulate longitudinal bone growth have been even more encouraging in cases of congenital femoral shortening and have shown significant stimulation of longitudinal bone growth after osteotomy. At the time of writing, it appears that osteotomy performed in the shaft adjacent to both upper and lower femoral epiphyses produces stimulation of longitudinal bone growth. This stimulation lasts for at least nine to twelve months, and, in some instances, even longer. In those patients in whom repeated fragmentation has been performed at nine-to-twelve-month intervals additional stimulation has been effected.

The first patient (Figs. 15-A through 15-D) we saw had approximately a two-inch discrepancy in leg length when he was four months old. Three fragmentations of the femur were carried out at intervals; the child now, at the age of four years, shows only one and one-half inches of shortening. A second patient's discrepancy was one-half of an inch when the child was twenty

FIG. 15-A

FIG. 15-B

Figs. 15-A through 15-D: J.F. Congenital shortening of the femur.
Fig. 15-A: November 19, 1954. Preoperative roentgenogram made when the patient was two weeks old; the difference in leg length is two inches.
Fig. 15-B: November 21, 1955. Two weeks after first fragmentation procedure.

FIG. 15-C

FIG. 15-D

Fig. 15-C: September 27, 1958. One day after the third fragmentation procedure. (The second procedure was done on November 8, 1957.)
Fig. 15-D: January 14, 1959. Roentgenogram made when the patient was four years and two months old; the difference in leg length is one and one-half inches.

months old; two years later, after one operation, the discrepancy was seven-eighths of an inch. The third patient, whose leg-length discrepancy was two inches when he was one year old, now, at the age of six years, has a discrepancy of three inches, after having undergone four operative procedures. The fourth child, who, at three months of age, had a leg-length discrepancy of one and one-half inches now, at the age of two years, has a discrepancy of two inches, having undergone two operations. If it is possible to maintain three inches or less of leg-length discrepancy as growth continues, an epiphyseodesis on the long leg at the appropriate time may result in approximately equal leg length, and amputation, which in all previous instances was inevitable, may not be necessary.

SUMMARY

Fragmentation, realignment, and internal fixation with an intramedullary rod have been used in the treatment of osteogenesis imperfecta, congenital pseudarthrosis of the tibia, resistant rickets, fibrous dysplasia, and congenital shortening of the long bones. The method has shown some promise.

The use of this technique to stimulate bone growth is still in the experimental stage. Although improved techniques for growth stimulation will probably replace this one, at the present time it appears that some amputations may be avoided by this procedure, pending the development of better methods.

The few patients with congenital pseudarthrosis whom we have treated by this method have responded favorably. The procedure may have something to offer, but too few patients have been treated to permit a true evaluation.

The use of intramedullary support in cases of osteogenesis imperfecta does not solve the basic error in bone pathology, yet it offers the most promising aid in management in the light of our present experience. The patients with severe cases are made more comfortable and are more easily handled from a nursing standpoint. Some children who would never have been able to walk are now ambulatory. This operation with fixation removes the fear of further refracture with its resultant deformities, and allows the patients to approach, more nearly, the normal activities of growing children.

In the field of orthopaedic surgery it seems probable that there are definite conditions in which the operation of fragmentation, realignment, and intramedullary fixation of long bones offers advantages that cannot be obtained by other presently known methods. If performed thoughtfully and carefully, the results should be quite rewarding.

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2. Stelling, F.: Personal communication.
3. Trueta, Joseph: Treatment of Length Discrepancy of the Lower Limbs. *In* Proceedings of The British Orthopaedic Association. J. Bone and Joint Surg., **38-B:** 934, Nov. 1956.

DISCUSSION

Dr. William M. Roberts, Gastonia, North Carolina: I was associated with Hal Sofield on the American Board of Orthopaedic Surgery when he first began to use the procedure just described. When I returned to Gastonia I too began using it, particularly in cases of osteogenesis imperfecta. Because my experience with the procedure has been confined to this disease, I was particularly intrigued to hear that its use has been extended to congenital pseudarthrosis and the other conditions discussed. I am sure all of us will be stimulated to use this procedure in these other conditions and, particularly, in congenital pseudarthrosis of the tibia.

The majority of the procedures performed at the North Carolina Orthopaedic Hospital were done by my associate, George Miller, and the resident staff. Twenty-six patients with osteogenesis imperfecta have been treated at the North Carolina Orthopaedic Hospital since 1951. Seven patients underwent multiple osteotomies and intramedullary rod fixation; a total of seventy-eight operations were performed (these, of course, included rerodding as the children grew). Twenty-nine procedures were performed on the tibia, thirty-one on the femur, and one on the radius. The age of the patient at the time of the first surgery varied from five to fourteen years. There were no cases of non-union or of postoperative infection. There were two cases of superficial infection, where the pin protruded through the anterior cortex and skin of the tibia. These infections cleared up quickly with antibiotics and rerodding was done without ill effects. We then lost these children to follow-up and have not been able to rerod them as they continue to grow. All of the patients operated on are now walking with braces. All of the children had blood transfusions at surgery and most of the operations on the lower extremity were done with tourniquet control. There were no deaths.

I want to thank the authors for their help in solving a problem that has long been a headache to orthopaedists who treat children. They brought us a good procedure which at first hand seemed radical; long experience and follow-up, however, have proved it to be safe, with few complications, most of which can be avoided if the principles laid down in this paper are followed carefully.

Survival of Patient with Hemophilia and Fracture of Femur

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Hemophilia has been recognized for centuries as a hazardous disease. A disastrous and even fatal outcome may follow accidental or surgical trauma to its victims. Fractures of any magnitude are especially ominous; and surgical procedures are carried out intentionally on hemophiliacs only on rare occasions.

There is lack of agreement as to the best course to follow in the management of surgical problems in the hemophiliac. Some writers state that surgical treatment is contra-indicated under all circumstances. Others advise against such treatment unless it is clearly evident that death will ensue if it is not undertaken [5]. Recent reports in the literature, however, attest to the fact that with proper management the hemophilic patient can withstand considerable trauma and even extensive surgical procedures. Successful mid-thigh amputations were reported by Crandon and associates and by Schuster. Walker and Desmond performed gastrectomy in hemophilic patients with good ultimate results. Thus, it would appear that as a result of the awakened interest in this disease and the availability of increasingly precise laboratory assays of coagulation factors, a decrease in timidity in managing the surgical problems of these patients has taken place. But it is generally agreed among all those concerned with the management of these problems that the conservative course of treatment must be followed whenever possible.

Whereas changes that occur in the joints as a result of repeated hemarthrosis are common in persons affected with hemophilia, changes in bones are rare. The pathological changes in bones are due to the pressure and erosion effect of local hemorrhages. Intra-osseous cavities may result, and these may occasionally develop into large expanding lesions with much bone destruction. The latter have been called hemophilic pseudotumors by some writers. Ghormley and Clegg, in 1948, reviewed the literature on hemophilic pseudotumors and reported six additional cases. In three of their reported cases, the pseudotumor occurred in the femur and was complicated by pathological fracture.

The occurrence of fractures, either pathological or non-pathological, in the hemophilic patient has been referred to in the literature. However, in a review of the literature, no description of the management and course of a specific severe fracture could be found. It is our purpose to report a case in which a fracture of the femur in a child with hemophilia was managed successfully by conservative means and to summarize the treatment of traumatic problems in the hemophilic patient.

REPORT OF CASE

An eight-year-old white boy was admitted to the hospital orthopaedic service on September 3, 1953, two hours after he had fallen off a bicycle. He had pain and swelling of the right thigh. He had been found to have hemophilia when he was eight months old. There was no family history of a bleeding tendency. On his first visit to the Mayo Clinic, on July 7,

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FIG. 1

FIG. 2

Fig. 1: Anteroposterior and lateral roentgenograms of right femur at time of injury.
Fig. 2: Eight weeks after injury.

FIG. 3

Six months after injury.

FIG. 4

Two and one-half years after injury.

1948, when he was three years old, he had been treated for an infection of the upper respiratory passages, and the diagnosis of hemophilia had been affirmed. From infancy until the present admission, he had had many hemorrhagic episodes, had required multiple blood transfusions, and had been in the hospital on numerous occasions for treatment of conditions related to his disease.

Physical examination revealed a mildly obese and well developed boy. His temperature was 99 degrees Fahrenheit, the pulse rate 90 per minute, the respiratory rate 20 per minute, and the blood pressure 100 systolic, 64 diastolic. He was in considerable pain. There were moderate swelling and marked tenderness over the right upper anterior part of the thigh. There was no evidence of impaired circulation in the distal part of the limb. Roentgenograms revealed a comminuted fracture in the upper third of the right femur (Fig. 1).

A Thomas splint was applied to the right lower extremity, eight pounds of skin traction was applied to the leg, and the extremity was wrapped from the toes to the groin with an elastic bandage. Ice bags were placed about the right thigh, and a transfusion of fresh whole blood was started. Manipulative reduction of the fracture was not attempted, despite the

relatively poor position of the fragments, because of the danger of increasing local hemorrhage.

Hemorrhage was controlled initially but repeated hemorrhagic episodes occurred during the patient's hospital stay which were characterized by sudden increases in the size of the thigh and a fall in hemoglobin. These were controlled by repeated small transfusions, as will be described.

Traction was maintained until November 5 (for approximately eight weeks), and the Thomas splint was removed five days later. At that time, roentgenograms showed persistent overlapping of the fragments, but considerable bone-callus formation (Fig. 2). The patient was dismissed from the hospital on November 21; he was using crutches.

He was admitted to the hospital again on December 29 for treatment of hemarthroses involving his right wrist and left ankle, which had resulted from a fall from his crutches and injury to these sites. He had no symptoms referable to his right thigh at that time; roentgenograms showed the fragments to be in the same position as previously with additional callus formation.

On March 30, 1954 (approximately six months after fracture), a roentgenogram revealed firm bone union in a circular fashion about the site of fracture (Fig. 3). The patient was walking with a slight limp and had half an inch of shortening of the right lower extremity. A roentgenogram made two and a half years after fracture (Fig. 4) showed firm bone union and minimum deformity. Clinical examination of the lower extremity gave negative results at that time. Frequent subsequent examinations have been made. Hemarthroses have occurred in many joints since the time of fracture, but the fractured femur gives no concern to the patient or to the orthopaedist, for there is normal function and appearance of the extremity. The management of hemophilia in general and in this patient in particular is described in the following paragraphs.

DIAGNOSIS OF CLASSIC HEMOPHILIA

A complete re-evaluation of the boy's hemophilic defect was undertaken when he was admitted with his fracture, since two variants of classic (antihemophilic globulin deficiency) hemophilia had been established since our earlier studies, one due to plasma thromboplastin component deficiency, the other to plasma thromboplastin antecedent deficiency. The plasma thromboplastin component[1] (or Christmas factor[3]) is characterized by its ability to withstand storage, to survive clotting and hence be present in serum, and to be adsorbed by chemicals such as barium sulphate and tricalcium phosphate. Antihemophilic globulin differs from plasma thromboplastin component in all three of the characteristics just mentioned. Plasma thromboplastin antecedent[14] has certain of the properties of antihemophilic globulin (non-adsorption by barium sulphate or tricalcium phosphate), as well as of plasma thromboplastin component (present in serum). The three hemophilias can be differentiated by coagulation tests based on the distinctive qualities of these factors or by cross checking with blood from patients known to have each of the three defects[12]. Since no patients were immediately available with these deficiencies, the former method was used in this case.

The coagulation time of whole blood of the patient was approximately one hour (normal, six to eight minutes) on this and many other occasions; the comparable clotting time of his plasma, tested at 37 degrees centigrade, was usually more than ten minutes (normal, less than two minutes). Since his prothrombin time was consistently normal, the evidence was strongly suggestive of a defect in the first step of clotting: platelet phospholipid plus antihemophilic globulin plus plasma thromboplastin component plus plasma thromboplastin antecedent yielding plasma thromboplastin. Were a defect to occur at any subsequent stage of clotting (cothromboplastic activation of the plasma thromboplastin, conversion of prothrombin to thrombin, and thrombic conversion of fibrinogen to fibrin), the prothrombin time would have been affected. Since the platelets were normal quantitatively, it was inferred that this child suffered from one of the three hemophilias[17]. This was confirmed directly.

Plasma Clotting Time[12]

The patient's oxalated plasma clotted in about 600 seconds, or longer, upon recalcification, when measured at body temperature. The addition of one vol-

ume of normal plasma to nine volumes of patient's plasma shortened the clotting time to 140 seconds. Comparable shortening was achieved by the addition of tricalcium phosphate-adsorbed, fresh, normal plasma (freed of plasma thromboplastin component by the adsorption) but there was no correction when aged, normal plasma was added (lacking antihemophilic globulin, but with both plasma thromboplastin component and plasma thromboplastin antecedent present). By a procedure as simple as the plasma clotting time, the diagnosis of classic (antihemophilic globulin lack) hemophilia was made.

Prothrombin Consumption [13]

If the serum of normal blood is aged one hour at 37 degrees centigrade, only slight coagulation activity remains. This may be demonstrated by determining the prothrombin time on one-hour-old serum, after the necessary addition of fibrinogen to the serum. Normal values are twenty seconds or more, while clearly abnormal are values of fourteen seconds or less (that is, excessive coagulation activity persists in the serum). This patient's prothrombin-consumption clotting times were low. Over the years they have varied from eight to eleven seconds. More sensitive than the plasma clotting time, this test introduces a quantitative note and indicates that this boy's hemophilia was severe.

Thromboplastin-Generation Test [2]

An artificial clotting system, complete but for prothrombin, can progress only through the first two steps of clotting (generation of plasma thromboplastin and its cothromboplastic activation); it is, therefore, possible to measure thromboplastin generation as an isolated phenomenon. The test for this consists in mixing serum and barium sulphate-adsorbed plasma; all the known clotting factors except platelets and prothrombin are present in this mixture. After adding a suspension of platelets, prothrombin alone is wanting. The amount of thromboplastin generated is measured at intervals by introducing plasma (containing prothrombin and fibrinogen) to the clotting system; the resulting clotting time reflects the amount of thromboplastin generated, and the speed of the reaction is a measure of the rate of generation.

Although the thromboplastin-generation test was not available at the time of this patient's accident, it has been performed on his blood a number of times since. As we perform the test [8], a normal yield of thromboplastin is indicated by a clotting time of eight to ten seconds reached in a period of nine to eleven minutes. When the patient's serum and his plasma yield only a very limited amount of thromboplastin (clotting time of twenty-five to thirty seconds) and at a slow rate (peak in about twenty minutes) and the patient's serum and normal plasma yield thromboplastin in a normal manner, plasma thromboplastin component and plasma thromboplastin antecedent deficiencies are excluded since both are characterized by abnormal generation with serum. Our patient's plasma, both with normal serum and with his own serum, produced equally abnormal generation of thromboplastin. This test constitutes the most precise method known today for the identification of classic hemophilia of the antihemophilic globulin-deficiency type.

TREATMENT OF CLASSIC HEMOPHILIA

The modern treatment of classic hemophilia [4] depends on three principles:

1. The concentration of antihemophilic globulin in the plasma of the severe hemophiliac is less than 1 per cent of normal;

2. Antihemophilic globulin is so labile that it survives less than twenty-four hours in the circulating blood of the hemophilic patient;

3. Even with the most careful of blood-bank collecting techniques, anti-

hemophilic globulin disappears fairly rapidly from citrated bank blood (50 per cent in four to seven days in our experience).

It is apparent, therefore, that the transfusion of one pint of blood (containing about 250 milliliters of plasma) could raise the concentration of antihemophilic globulin in our patient to only about 20 per cent of normal, assuming that his plasma volume was approximately 1,200 milliliters. During the succeeding twenty-four hours, this concentration will have fallen to about its pretransfusion level. The peak of concentration of 20 per cent is attainable only if the donor blood at the time of transfusion has a completely normal concentration of antihemophilic globulin.

The minimum concentration of antihemophilic globulin required to prevent bleeding is not clearly established, but probably lies between 5 and 20 per cent of normal [4,18]. Our personal observations indicate that the lower value is sufficient to halt the bleeding associated with minor trauma, but a level as high as 10 per cent of normal may be insufficient to control intraperitoneal hemorrhage or the bleeding accompanying a surgical procedure.

On the basis of these principles, blood not more than forty-eight hours old (usually less than twenty-four hours) was administered to this patient. Because of the rapid decay of antihemophilic globulin *in vivo*, volumes of one-quarter to one-half pint were given several times during each day rather than an entire pint at one time, except initially. This practice of frequent small transfusions is based on the clinical observation that hemorrhage is better controlled, and on the theoretical ground that an antihemophilic globulin titer maintained at 5 to 10 per cent of normal is more satisfactory than a titer fluctuating between 0 and 20 per cent.

Despite this therapy, this patient continued to have episodes of further hemorrhage which were manifested by sudden increases in the size of the tumor of the thigh and by decreases in the concentration of hemoglobin in the blood. Increased volumes of transfused blood were used in these instances; this, together with immobility of the extremity, seemed to control the bleeding reasonably well.

COMMENT

The diagnosis of hemophilia of the classic type (lack of antihemophilic globulin) was established in this patient by the finding of a deficiency of a labile, non-adsorbable substance affecting the initial step of blood coagulation. The degree of severity was maximum as estimated from the results of the prothrombin-consumption and thromboplastin-generation tests which, according to Brinkhouse and associates, signifies a concentration of antihemophilic globulin of less than 1 per cent of normal.

The control of bleeding was effected in part by the administration of the freshest available whole blood preserved in citrate-dextrose anticoagulant and in part by immobilization, compression, and elevation of the limb. An attempt was made to maintain the level of antihemophilic globulin above 5 per cent of the concentration found in normal persons. The concentration was estimated from the blood volume of the boy and the volume of transfused blood, corrected for the known rapid decay of antihemophilic globulin in the circulation. About half is destroyed in six hours, and three-fourths in twelve hours.

Laboratory control of the coagulation status of hemophiliacs is none too satisfactory. Elaborate titrations of antihemophilic globulin are difficult and too time-consuming to be practical. Performance of the thromboplastin-generation test also requires too long a time to furnish any immediate practical results. The simpler prothrombin-consumption test cannot yield an answer in less than about one and a half to two hours. One is forced, therefore, to use whole blood or plasma coagulation times, inaccurate as they may be, if up-to-the-minute knowledge of the degree of abnormality is required.

The question may be raised with good reason as to whether frequent coagulation tests are actually required in the treatment of these patients. The greater our experience, the fewer tests we carry out. Since one can estimate reasonably well the amount of antihemophilic globulin present in the patient at any time from the volume and age of the blood or plasma given, it is not, as a rule, too difficult to keep the level of antihemophilic globulin at about 5 per cent of normal. At this level, little bleeding usually occurs. Only when a severe infection is present do the calculations become misleading; presumably, the antihemophilic globulin is degraded at an accelerated pace.

Our program of therapy in this patient, and in other hemophiliacs undergoing surgical treatment, is: (1) a priming dose (500 to 1,000 milliliters) of blood immediately preoperatively, or immediately after an injury; and (2) transfusion of small amounts of fresh blood (100 to 250 milliliters), or of fresh plasma (50 to 100 milliliters) if the concentration of hemoglobin is high, two to four times daily until there is no further clinical evidence of bleeding, then once daily for several days until convalescence is established. With such a regimen, Mayo Clinic patients with one or another of the three types of hemophilia have been subjected to gastrectomy, nephrectomy, transurethral resection, and removal of a ruptured intervertebral disc, as well as other, lesser procedures, without a fatality in the past six years.

The control of hemophilic bleeding would be simplified immeasurably if concentrates of active antihemophilic globulin were available. Experimental work [11] with such preparations of bovine origin is being conducted, but it is too early to evaluate the results. Commercial preparations of lyophilized, very fresh plasma are available and are stable more or less indefinitely. Fresh plasma, frozen promptly and administered as soon as thawed, is also effective; occasional batches of such plasma have shown disappointing concentrations of antihemophilic globulin, suggesting some deterioration before freezing, after thawing, or perhaps during the storage period.

Probably, the single most important item in the treatment of a hemophiliac is prompt identification of the nature of the defect as well as some quantitative measure of the degree of abnormality. The administration of two-week-old banked blood is almost useless if the patient lacks antihemophilic globulin, but is entirely satisfactory if he lacks plasma thromboplastin component.

Although this child's disability was complicated by classic hemophilia, it was fundamentally an orthopaedic problem. It is well known that fractures of the shafts of long bones adapt well to variations in length and alignment at this age (eight years). The satisfactory morphological and functional result in this patient's limb is further proof of this. Manipulation at the time of fracture was contra-indicated because of the possibility of increasing the hemorrhage.

In the management of a hemorrhagic episode incident to trauma in a hemophilic patient, the type of trauma and consequently the location and severity of the hemorrhage are factors to be considered. Internal abdominal bleeding is much more difficult to diagnose from the standpoint of exact site of bleeding and the standpoint of control than is hemorrhage into a limb [5]. The measures employed in the management of hemorrhage into a limb are: (1) immobilization with the joints in a position of function, (2) application of pressure to and elevation of the limb, and (3) provision of comfort for the patient by local application of ice and by sedation and administration of analgesics. Bleeding into muscles or deep tissues may have grave consequences, causing pressure on nerves and vessels, and permanent contractures of muscles. Paralysis or even gangrene may ensue [10]. This bleeding should be prevented or controlled as far as is possible by the means just mentioned. Bleeding from open wounds can be controlled by pressure over the site of bleeding, the application of topical coagulants such as Russell viper venom, topical thrombin, and absorbable gelatin sponge (gelfoam), and the ligation of larger bleeding vessels.

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A Ten-Year Analysis of Intertrochanteric Fractures of the Femur*

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In January 1947, at The American Academy of Orthopaedic Surgeons, a paper was read discussing 133 consecutive trochanteric fractures of the femur treated at St. Luke's Hospital. This paper is a continuation study of such fractures during the ten-year interval which followed, from January 1947 to January 1957.

In this survey are included 239 consecutive trochanteric fractures of the femur. The 80 per cent increase in the number of these fractures treated with internal fixation indicates acceptance by the general staff of the fact that these severe injuries are best managed by Jewett-nail fixation.

When the 1947 report was written, internal fixation of these fractures was just becoming popular. A third of the fractures reported in the first series were treated by traction. There were only five patients treated electively by traction in the present series and one treated by cast. Despite a considerable increase in the number of these injuries treated, the number treated by traction has dropped. Of the patients in this series, 97.5 per cent were treated by internal fixation.

AGE AND SEX

Trochanteric fractures occur most frequently in elderly women, at an age when osteoporosis is common and other pathological conditions are well established. The average age in this series was seventy-five years—the youngest was twenty-three years and the oldest 101. Females predominated (88.7 per cent) as compared with males (11.3 per cent). This figure emphasizes the fact that the bone structure and configuration of elderly women tend to be less resistant to trauma than the bone structure and configuration of men of the same age.

RACE

In the previous paper, it was noted that no Negro patient was admitted with a trochanteric fracture. In the present series, three Negro patients were treated for trochanteric fracture, an incidence of 1.2 per cent.

We feel this low incidence is not due to either a racial tendency to a stronger skeletal frame, or to a delay in the onset of senile osteoporotic changes in the Negro, but is due to the fact that St. Luke's Hospital has no ambulance service and most such patients go to a nearby city hospital.

LOCATION OF THE FRACTURE

In the previous decade there was a preponderance of fractures on the left, the ratio being two to one. In the present series, the relationship was more nearly equal, with 44 per cent of the fractures being on the right and 56 per cent on the left.

For purposes of classification these fractures have been grouped into three types [1]. The commonest were the pertrochanteric fractures, 60.3 per cent. The

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next largest group were paratrochanteric (base of the neck), 18.5 per cent. Subtrochanteric fractures were the least common, 14.7 per cent. The remaining 6.5 per cent consisted of fractures so comminuted as to be combinations of the other types. Two patients had combined intracapsular and trochanteric fractures; both patients did well.

INCIDENCE OF MULTIPLE HIP FRACTURES

These patients showed a high incidence of fracture of the other hip, or refracture of the same hip occurring on a separate occasion. Two hundred and thirty-nine fractures in this series occurred among only 232 patients. Seven patients sustained a trochanteric fracture of the other femur at another date during this ten-year period.

When intracapsular fractures as well were taken into account, it was found that thirty-four (16.4 per cent) of the patients had suffered multiple hip fractures. Two patients had three separate fractures at the hip. The fact that when an elderly woman sustains a trochanteric fracture she has a 16.4 per cent chance of having another fracture at the hip at some time is alarming. This fact should direct one's attention to the underlying instability and inherent weakness of the bone structure of these elderly people which predispose them to this injury; it should lead one to do something about it. More widespread use of measures to correct or prevent osteoporosis should be instituted. The patient should be protected, instructed, and guided and, to some extent, their activities should be permanently controlled. Their surroundings should be freed of potential dangers for the aged such as loose rugs, slippery floors, scattered toys, stray animals, poor lighting, and the like. For some patients whose general condition (senility, for example) makes future falls and fracture almost a certainty, total restriction of independent ambulation is indicated after recovery.

Two of the refractures at the hip in this series occurred during the convalescent period in patients unsure in the use of crutches. Thirty-one occurred years before or after the present trochanteric fracture and had no direct relationship to it. In only one patient was there simultaneous fracture at both hips.

ASSOCIATED DISEASES AND PATHOLOGICAL CONDITIONS

The usual problems of advanced age, such as malnutrition, arteriosclerosis, heart disease, diabetes, renal insufficiency, senility, arthritis, hemiplegia, and residuals of various operative procedures were frequently noted in this group. In addition, three of the fractures were pathological, two caused by carcinoma and one by Paget's disease (Figs. 1-A and 1-B). This puts the problem in proper perspective. The obvious fracture at the hip may mask the presence of the serious conditions just mentioned. Satisfactory results can only be achieved by constantly keeping in mind that the problem is not only orthopaedic, but that the services of a full complement of the whole medical staff must be employed. The general condition of these patients, superimposed on their age, rarely made them good operative risks. Because of this and the advanced age of this group, a final follow-up study, although often possible, was not apt to be long.

TYPE OF INJURY PRODUCING THE FRACTURE

The mechanism of injury varied. Of the patients, 63.9 per cent sustained their injuries in falls at home. Falls in the street accounted for 19.8 per cent. Falls in our hospital, causing fracture, accounted for 7.2 per cent, although these patients had been admitted for some other condition. Violent trauma accounted for only 6.8 per cent. The cause of the fractures in 2.3 per cent was unknown.

This indicates that the same prophylactic care of the surroundings of the aged, needed to prevent falls after operation, should be employed whenever there is an elderly person in a home. Many of these fractures need never have occurred had there been a little care and foresight.

TREATMENT

Of the 239 trochanteric fractures ten were not operated on. Four patients were too ill to permit surgery; they died, on the average, five days after admission to the hospital. One death was from bronchopneumonia, two from cerebral vascular accidents, and one from a skull fracture.

Five patients were treated by traction electively. One had a deep buttock burn; the second was admitted sixty-three days after injury; and the third had an undisplaced fracture. The fourth had a pertrochanteric fracture as well as an undisplaced vertical fracture of the head and neck of the femur (Fig. 2); fixation of any type would have separated the fragments. The fifth, with negative roentgenograms, initially, was treated by traction; later, roentgenograms showed a healing fracture.

One patient was treated with a double plaster spica. This young man, who had hemophilia, was the only one with bilateral simultaneous hip fracture, one intracapsular and the other trochanteric. His bleeding could not be controlled

FIG. 1-A

FIG. 1-B

Fig. 1-A: Roentgenogram showing a trochanteric fracture on which operation was performed. This patient had extensive adenocarcinoma involving the upper part of the femur and the pelvis. The limb remained stable for twenty-four months, at which time the patient died.

Fig. 1-B: Subtrochanteric fracture in Paget's disease. Fixation was performed with a spline. Union here, as in other fractures through bones involved by Paget's disease, is not delayed.

and he died in the hospital of a cerebrovascular accident 120 days after admission.

The remaining 229 trochanteric fractures were treated with internal fixation. All but two were immobilized with a one-piece Jewett nail. One was fixed with a blade plate and one with a spline. The average interval of time between injury and operation was 2.9 days. Most of this delay occurred prior to admission. We believe that prompt surgical fixation is mandatory, and that many patients apparently doomed can thereby be saved.

OPERATIVE TIME AND NAIL PLACEMENT

The average operative time was 55.9 minutes. This includes reduction, surgery, and roentgenograms. The time varied from fifteen to 135 minutes. Some extremely comminuted fractures required several insertions of the nail to obtain satisfactory placement.

The average number of nail insertions was 1.54 per operation; 144 were done with one drive. The greatest number of failures occurred in the fractures where the nails were placed too high or anterior in the head of the femur (usually single drives). In the multiple-drive group, removal of the nail from a poor posi-

FIG. 2

FIG. 3-A

Fig. 2: Roentgenogram showing a vertical fracture of the femoral neck, associated with a subtrochanteric fracture. The patient was treated by traction because of the danger of displacing intracapsular fragments by any internal fixation device.

Fig. 3-A: This anteroposterior roentgenogram of a fracture was made at operation and shows the long Jewett nail.

tion and reinsertion in a good position lowered the incidence of failures of union, and carried no demonstrable adverse effects on the over-all final result.

NAILS USED

The length and the angle of the Jewett nails varied over a wide range; in 76 per cent the angle used was 130 degrees. The length of the nails varied from one and one-half inches to three and three-fourths inches, but 90 per cent of them were three to three and one-half inches.

On the follow-up roentgenogram 10 per cent of these nails were seen to have penetrated the articular cartilage. In retrospect, we believe that some of the nails could have been shorter. However, when the head and neck fragment is short, the surgeon is faced with the choice of a short nail and instability, or a long nail with later possible penetration (Figs. 3-A, 3-B, and 3-C). In such cases, we prefer stability and possible penetration. A penetrating nail can later be removed, but malunion is hard to accept.

WOUND HEALING

Surgical incision in patients at this age carries with it a high incidence of wound complications. Despite this, there were only five recorded hematomata; four of these became infected. All healed, although one took five months. All five patients survived. There were also six skin infections because of silk sutures, which healed promptly after removal of the sutures.

POSTOPERATIVE CARE

Our concept of the care of these patients envisages treatment by the complete medical and orthopaedic staff from the time of injury until discharge.

Meticulous nursing care influences the general outcome more than any other

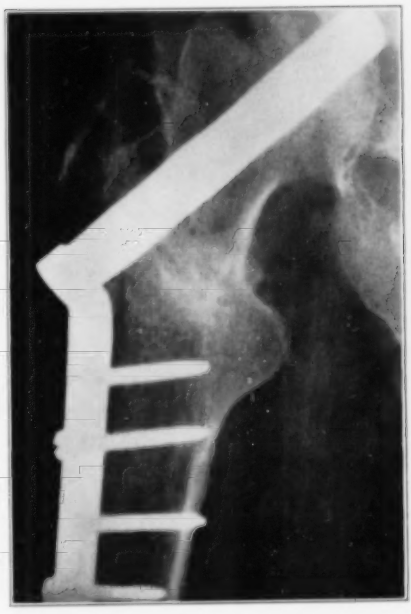

FIG. 3-B

FIG. 3-C

Fig. 3-B: The roentgenogram made after operation shows penetration of the nail as healing occurs.

Fig. 3-C: Roentgenogram three years after operation shows the fracture healed and the nail removed. The hip was asymptomatic, with a full range of motion.

single factor. These patients are turned frequently to prevent stasis. Russell's traction is used only during the first few postoperative days. The patients are out of bed, on an average, fifteen days after operation.

AMBULATION

The patients were taught crutch-walking when vision, strength, balance, and general condition permitted. An indeterminate number of these patients were not walking when fracture occurred. Twenty-one patients died before they could walk, and forty-nine patients left the hospital before they became ambulatory. Those patients with nailed fractures who did walk did so, on an average, thirty-eight days after operation. The five patients treated electively by traction walked, on an average, eighty-seven days after operation—forty-nine days later than the patients who were treated surgically.

DURATION OF HOSPITAL STAY

The average period of hospitalization was fifty-three days for patients who were operated on, and 100 days for the five patients treated by traction. Patients treated surgically required half the hospitalization that was needed for the patients treated by traction.

FATALITIES DURING HOSPITALIZATION

Twenty-four of the patients who were operated on in this series (10.5 per cent) died before discharge from the hospital. Three patients died within seventy-two hours; the earliest, twenty-four hours after surgery. The average time of death was thirty-four days after operation. Four patients treated by traction and the one immobilized in a plaster spica also died.

The causes of death in the hospital were: pulmonary emboli in six patients, congestive heart failure in six, myocardial infarct in five, pneumonia in two,

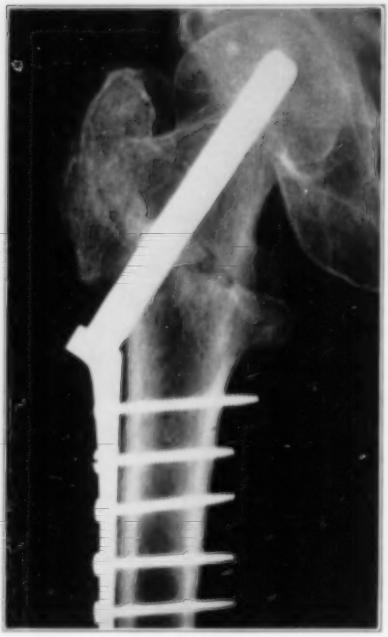

FIG. 4-A

FIG. 4-B

Fig. 4-A: An intertrochanteric fracture which was converted to subtrochanteric by introduction of the nail and reduction of the fracture.

Fig. 4-B: Roentgenogram made four and one-half years after operation shows the fracture to be healed; this occurred in the usual time and without any untoward complications.

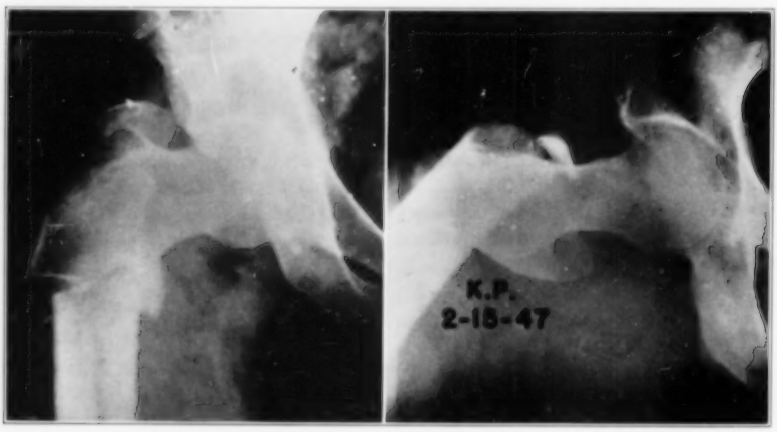

FIG. 5-A

Anteroposterior roentgenograms showing onset of a subtrochanteric fracture.

and general malnutrition and arteriosclerosis in two. Uremia, carcinomatosis, and bleeding gastric ulcer, respectively, were the causes in three patients. One patient treated by cast had hemophilia; he also died in the hospital.

NON-FATAL COMPLICATIONS

The incidence of non-fatal complications was: decubitus ulcer of the heels, 2.6 per cent; decubitus ulcer of the sacrum, 5.3 per cent; senile deterioration, 7.9 per cent; thrombophlebitis, 6.3 per cent; cardiac decompensation, 2.6 per cent;

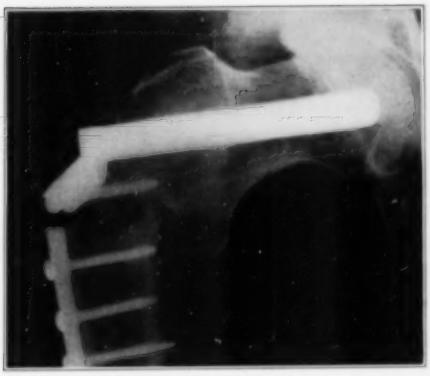

FIG. 5-B

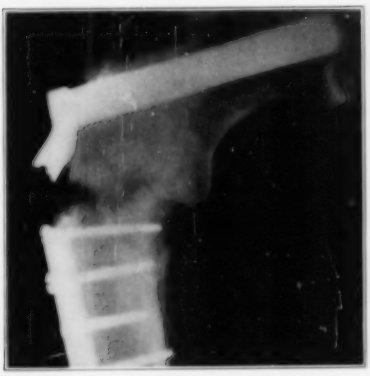

FIG. 5-C

Fig. 5-B: Roentgenogram showing fracture of an old type of Jewett nail through the upper part of the plate two months after open reduction and insertion of the nail.
Fig. 5-C: Roentgenogram showing fracture of a second Jewett nail, ten months after onset of the subtrochanteric fracture.

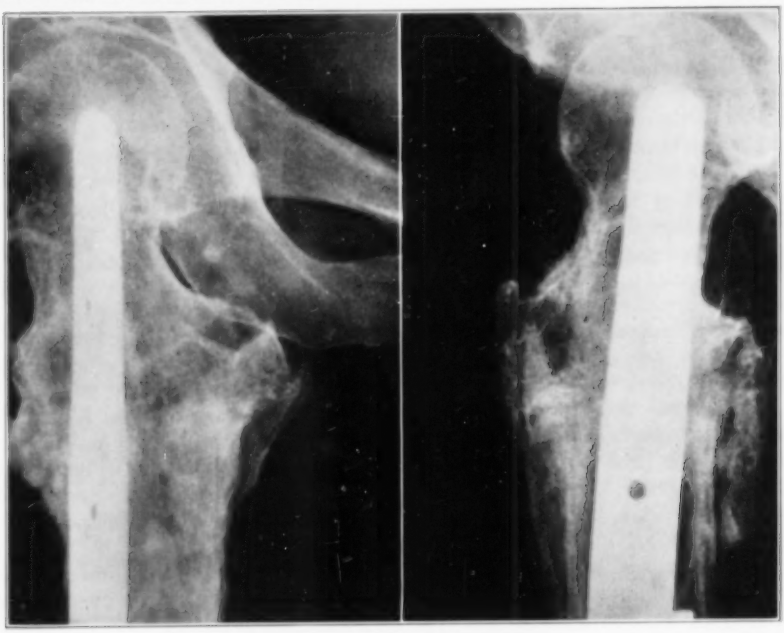

FIG. 5-D

The subtrochanteric fracture finally united in full valgus with spline fixation—the sixth operative procedure. This roentgenogram was made five years after fracture.

pulmonary emboli, 2.6 per cent; pneumonia, 2.6 per cent; cystitis, 1.7 per cent; and cholecystitis, 1.7 per cent.

There was also one case each of diabetic gangrene of the foot, penicillin reaction, cerebrovascular accident, peroneal palsy, pulmonary atelectasis, uremia, and postoperative shock. Delerium tremens developed in two patients.

Severe senile disorientation demanding permanent institutional care developed in 3.5 per cent of the patients who were operated on. (Senile changes were frequently reported to have been present before fracture.) A comparison of this disastrous complication, which developed in 11 per cent of the patients who were treated conservatively, with the lower percentage in the patients who were

treated surgically, would indicate that the latter patients had a better outlook in this respect.

FOLLOW-UP

The average length of follow-up for all patients discharged from the hospital was 32.7 months. Of the 232 patients studied, eighty-one (34.9 per cent) are dead. Fifty-three (22.8 per cent) are alive. Ninety-eight (42.3 per cent) are unobtainable for examination at this time.

Of the patients whose present status is known, 60.5 per cent are dead and 39.5 per cent, alive. Inasmuch as the average age of these patients was seventy-five years at time of fracture, this is not surprising.

ROENTGENOGRAPHIC EVALUATION

Ninety-three per cent of the reductions were estimated by roentgenogram as good; 6.4 per cent were termed fair; and 0.6 per cent were determined poor.

In evaluating the placement of the nail in the anteroposterior view, it was found that 5.5 per cent of the nails were placed in the upper segment of the femoral head, 23.2 per cent in the middle, and 71.3 per cent in the lower portion. In the lateral view, 14.3 per cent of the nails were in the anterior, 39.3 per cent in the middle, and 46.4 per cent in the posterior portion of the head. Any nail anterior and high is poor, and one either anterior or high is questionable. Other placement is acceptable.

On the basis of the above criteria, it was judged that 80 per cent of the nails were well placed, 16 per cent questionably, and 4 per cent poorly placed.

Of the well placed nails, only 0.8 per cent failed. The questionably placed nails failed in 34 per cent (cut out usually, non-union in one). Poorly placed nails, occasionally accepted in the less severe fractures, failed in 20 per cent.

The time of union, on the average, was 4.5 months for the operative series and six months for those treated by traction. The patients who were operated on were discharged prior to union of fracture, but those treated by traction had to remain hospitalized pending complete consolidation of the fracture. This further indicates the contrast between the surgically and the conservatively treated patients.

A trochanteric fracture may be converted to a subtrochanteric fracture as the nail is being driven in (Figs. 4-A and 4-B). This sometimes occurs when an attempt is made to produce a valgus position of the proximal fragment. In this series eleven (6.1 per cent) were so changed. Follow-up examination showed that this made no difference with regard to the stability of the fracture or the date of healing.

The estimated time of healing was essentially the same in the intertrochanteric, paratrochanteric, and subtrochanteric fractures. It depends more on the stability of fixation than on the type of fracture.

There were two non-unions. One of these patients now walks with considerable difficulty with two crutches. The other, although using a cane, has pain. Both of these patients have what amounts to a McMurray osteotomy. In each instance the original nail fractured. In one it was replaced, and in both the nails were finally removed.

There was one fracture which, after a delayed union, finally healed after bone-grafting. This patient, the only one in the series in whom avascular necrosis developed, is considerably disabled.

NAIL FAILURES

Nine Jewett nails broke and one bent—4.4 per cent. In three of these patients the nails were left in place and the fractures united, whereas in three others the fractures were renailed, resulting in one union, one non-union, and one rebroken nail. In two others the nails were merely removed; the fracture united in one

and non-union developed in the other. One patient had six operations; two Jewett nails broke and the fracture finally united after fixation with a spline holding the proximal fragments in full valgus (Figs. 5-A through 5-D).

Twenty-three nails (10.5 per cent) penetrated the femoral head. In nineteen patients symptoms did not warrant removal of the nail, and in four the penetrating nails were removed because of pain. None of the nails placed low and posterior in the region of the calcar penetrated the head. Twelve nails cut out. In three additional patients the nail shifted. In these, the nail position accepted was either too high, too anterior, or both. In one instance (a pathological fracture), the screws pulled out after operation. Since solid, one-piece Jewett nails were used, there were no failures due to a motion developing at the joint between the nail and plate.

Fourteen patients had more than one operation to realign the fragments, to replace broken nails, to graft for delayed union, or to remove the nail. Twelve had two operations, one four operations, and one six operations. In two patients osteotomies were done to secure increased valgus position. Three patients had secondary bone-grafting, and the fracture united. Nine nails were removed because: three were broken, four penetrated, one bent, and one for local tenderness.

CONCLUSIONS

1. Treatment of trochanteric fractures of the femur has become that of surgical fixation. The presence of associated geriatric pathology and complications demand team work from the medical, urological, surgical, and orthopaedic staffs.

2. There is a 16.4 per cent chance that a patient with a trochanteric fracture will, at some time, sustain another separate hip fracture. This indicates a need for permanent protection.

3. The original placement of a one-piece Jewett nail, to a large part, determines the outcome. Multiple drives to obtain good position are acceptable and do not adversely influence the end result.

4. Where fixation demands a fully driven nail, the possibility of its later penetration should be accepted.

5. Failure of metallic fixation devices is bound to occur, in regard to both stability in osseous structure and fatigue fracture of the implant. Even if reasonable design of the appliance is present, and its internal structure has been tested by accepted methods, a small percentage of such fatigue fractures should be considered as inevitable.

REFERENCE

1. Cleveland, Mather; Bosworth, D. M.; and Thompson, F. R.: Management of the Trochanteric Fracture of the Femur. J. Am. Med. Assn., 137: 1186-1190, 1948.

DISCUSSION

Dr. Carlo S. Scuderi, Chicago, Illinois: One can hardly discuss a paper that has been so well presented and well organized. I can only re-emphasize some of the important points which were brought out by the authors. It was somewhat surprising, and interesting to me that the ratio of fracture in male and female patients was eight to one. Because I have charge of one of the male fracture services at the County Hospital, I might have a tendency to be a little bit biased, but I know that in my own private practice the ratio doesn't seem to be that high.

The average age of seventy-five shows that these patients were not in the best health, and I feel that this is accountable for the three surgical deaths. If a patient survives the first three to five days after operation and then dies of something else, you shouldn't blame the surgeon. So, I think, this is a very acceptable figure and is something that all of us will have great difficulty in equaling.

I was impressed with the fact that the authors' experience and mine were similar; that if the nail was too far anterior and superior, it had a greater chance of failure than that which was inferior and posterior.

The authors are to be complimented on the operative time—an average of 55.9 minutes. In the operation that took fifteen minutes the patient must have come in with an open fracture in the well dissected trochanteric area. I will say, however, that 55.9 minutes, with

roentgenographic control, means that there was excellent cooperation and a very skillful operative team. I think all of us would do well if we could come out with this average.

The authors used the Jewett nail exclusively. At the present time, I also use the Jewett nail, but I feel that any one-piece nail is acceptable; there is no reason why the Neufeld nail shouldn't work just as well, except that I have the equipment for putting in the Jewett nail and that is why I use it. Some time ago, in complete despair, we quit using any type of nail and blade attachment; there wasn't one made by man that didn't come apart somewhere along the line in our hands. How they do it, I don't know, but we tried them all and we feel that they ought to be in one piece when you start with them so you won't have to worry about their coming apart. It is very difficult to explain to friends, relatives, and the referring doctor why the bolt is on the sciatic nerve and the nut is up underneath the femoral artery, and we have eliminated that complication.

The percentage (10 per cent) of penetration of the nail was very interesting, because I have had similar experiences. Invariably, if I don't pay special attention, I use a nail that is a little bit too long. It looks good on the original roentgenogram made in the operating room, but because there is some magnification the tip of that nail is closer to the cartilaginous border of the head than one thinks. I have almost made it a hard and fast rule that I never use a nail that is longer than three inches, and I have yet to regret it. As soon as I start getting up to a nail from three and one-half to three and three-quarters inches long, I find, six months later, that most of those nails have penetrated. I err on the other side of being a little bit short, but so far I have had none pull out of the proximal fragment.

It is very nice to see this large statistical series and to learn that the patients who are operated on got well and left the hospital with fewer complications than the ones who were treated by traction. This is a marvelous statistical study; it is a series of cases that we can all learn from. The few unfortunate accidents and complications which the authors reported I am sure we have all encountered, and I think that their statistical figures, their operating time, and their low mortality is most commendable.

Dr. Mather Cleveland (closing): On any paper in which there are a great many names, there are always two classes of workers—the drones and the workers. I am distinctly a drone on this. I am extremely grateful to Dr. Scuderi for not asking any embarrassing questions that I couldn't have answered.

There are only two or three things that I would like to emphasize, and these are that there were only two patients, as far as we know (and we don't know everything about all of them), whose fractures failed to unite and only one instance of avascular necrosis. That, of course, is in marked contrast to the intercapsular fractures. Fourteen of the 234 patients treated surgically (about 6 per cent) required subsequent surgical procedures to realign the fracture, to replace broken nails, to remove penetrating nails, which cause symptoms, or had to have bone-grafting done for delayed union. I think it is interesting that considering the age of the patients this trochanteric fracture is attended, for the most part, with a high degree of union.

Radiosodium Clearance Rates as Indicators of Femoral-Head Vascularity*†

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Avascular necrosis of the femoral head is an important complication of trauma and disease of the hip joint. In particular, avascular necrosis of the femoral head occurs in from 17.8 per cent [6] to 33 per cent [5] of cases of fracture of the femoral neck and in 15 per cent [2] to 30 per cent [11,21] of cases of dislocation or fracture-dislocation of the hip joint.

This paper presents a preliminary report of a method for the early diagnosis of such avascularity of the femoral head, recently described by us [12]. Experimental results will be presented, and the clinical use of the method will be described.

METHODS AVAILABLE AT PRESENT

There are five methods available for diagnosing avascular necrosis of the femoral head.

Roentgenography

The roentgenographic appearance of the relative increased density of the femoral head when compared with surrounding atrophic vascular bone may enable one to make a diagnosis of avascular necrosis as early as three to four weeks after injury. Sometimes, however, many months elapse before such density differences are unequivocal. Roentgenography offers little help when the patient is being treated immediately after injury.

Histology

The second method is that of bone biopsy. Here, a small punch biopsy of the femoral head may enable the pathologist to distinguish between dead and live bone as early as two to three weeks after injury. This time must elapse to allow bone and marrow cells to be autolyzed. No differences will be distinguishable immediately after injury. The lacunae will still contain stainable nuclei and so will the marrow spaces.

Phlebography

Methods are presently being developed [8] to attempt to assess the vascularity of the femoral head by the injection of a radiopaque dye into the head and the observation of its passage out along the veins. The method is open to the criticism that the injected material, which is two milliliters or more in quantity, might find its way out along the veins even if the arterial blood supply was cut off. Another objection to this method is the impossibility of obtaining anything like a quantitative result by such a technique.

Intramedullary Blood Pressure

Work is at present being conducted by Stein and his associates [19,20] on the

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estimation of intramedullary blood pressure to detect the presence or absence of circulation in the bone; the results are not yet available.

Studies of Radiophosphorus Pickup

The fourth method available for the study of avascular necrosis of the femoral head is that of radiophosphorus pickup. The P^{32} may be given intravenously, and the amount of pickup by the femoral head may be assayed about ninety minutes later by one of two methods.

In Tucker's method [1,22] a small piece of the femoral head is removed along with a piece of presumably vascular bone from the greater trochanter. The specimens are ashed, and then the radiation is counted. By comparing the radiation from the two pieces of bone, a ratio is arrived at which indicates the amount of P^{32} pickup by the femoral head. This method takes some time to perform carefully, and the results are not available during the operation. In addition, the specimen from the femoral head may be contaminated, during its removal, by blood containing P^{32}, giving a falsely high pickup.

In the method of Boyd, Zilversmit, and Calandruccio the assay of the P^{32} pickup is made by the insertion of a probe Geiger-Müller tube up a hole which is made by placing a guide wire into the femoral head. The probe is sensitive to beta radiation and records the radioactivity of the femoral head into which it is inserted. However, beta radiation is rapidly filtered out by tissues, especially bone, and the probe is relatively insensitive to radiation from bone which is more than two or three millimeters away. The passage of the probe through normal trochanteric bone filled with blood containing P^{32} may lead to contamination of the probe and thus to falsely high readings. There is no doubt that studies of radiophosphorus pickup are a valuable experimental tool in assessing bone vascularity [13]. However, we feel that some other isotopes might serve the surgeon's purposes better, especially when an immediate result would be so valuable.

Radiosodium Clearance Studies

Previous work on avascular necrosis of bone using radioisotopes depended on the pickup of the element by the bone. It appeared that the clearance of a radioactive element from a deposit in bone could be followed by surface counting methods if the element emitted gamma photons which will penetrate tissues freely. The method of assessing bone vascularity presented here is a development of the work of Kety [9,10]. Smith and Quimby [17,18] first presented a method of assessing peripheral circulation using radiosodium. The isotope was injected intravenously, and its entry into the peripheral tissues was assayed by counting from the body surface. Kety [9,10] developed the method of injecting Na^{24} intramuscularly and then tracing its rate of removal by the circulation by taking counts over the deposited isotope for ten minutes. Other workers have continued to use the Na^{24} clearance technique in the study of various aspects of the effects of peripheral vascular disease on muscles [3,7,14,15,23,24].

The suitable isotope appeared to be Na^{24} rather than the longer-lived Na^{22}. Na^{24} has a half-life of 15.06 hours; this rapid decay greatly increases the safety factor to the patient. Most disintegrations of Na^{24} give a beta particle of 1.39 million electronvolts and two gamma photons with energies of 1.38 and 2.76 million electronvolts. These gamma photons easily penetrate body tissues including bone. Surface counting techniques may thus be used.

The difficulty in applying this technique to bone was introducing the radiosodium into the bone and of holding it there for ten minutes while counts were taken. No leakage can be allowed as this would lead to a false fall in local radiation. The syringe used to inject the isotope must be emptied as completely as possible so that there will be the lowest possible residual radioactive saline solution in the syringe which, consequently, would not be available for clearance by the circulation. The injected mass must not be under pressure or it may escape along

open veins even if there is no arterial flow. The syringe has to deliver a safe and thus a small amount of Na^{24} and yet give a starting count sufficiently above the background to allow counts to be taken for short periods of time which are nonetheless statistically valid.

The Radioisotope Syringe

A metal syringe (Fig. 1) was developed in cooperation with James Hite, Chief Engineer of Zimmer's Manufacturing Company, Warsaw, Indiana. Both the barrel and the plunger are made of stainless steel. The barrel is strong enough to be inserted into bone without fear of its bending. The syringe was designed in two sizes: a small one for use in the animal experiments and a larger one for use in adult human patients; the larger one is seven inches long and one-quarter of an inch in diameter.

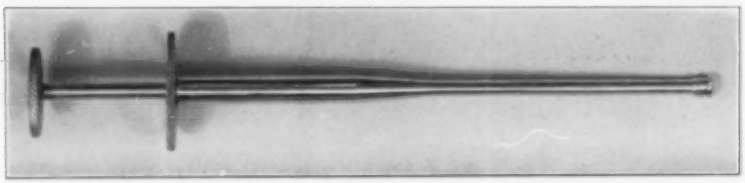

FIG. 1

The stainless-steel radioisotope syringe is shown assembled. The large model for use in human adults is seven inches long, and the narrow part of the barrel has a diameter of one-quarter of an inch.

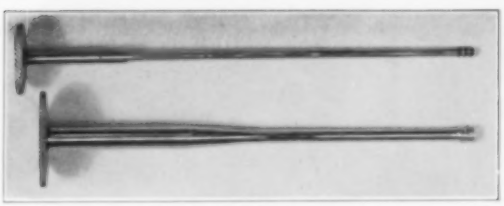

FIG. 2-A

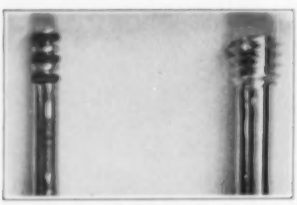

FIG. 2-B

Fig. 2-A: The metal syringe is shown disassembled. The threaded portion of the plunger can be seen. Filling and emptying of the syringe are accomplished by screwing the plunger in or out of the barrel, which gives good control of these actions.

Fig. 2-B: The ends of both the barrel and the plunger of the syringe are shown in greater detail. On the left can be seen the three O rings in their grooves in the end of the plunger. There is little room for radioactive material to be left inside the syringe after emptying. On the right of the picture the end of the barrel of the syringe with its coarse threads and one of the self-tapping flutes can be seen.

The plunger is screwed home into the barrel in order to effect complete control over filling and emptying (Fig. 2-A). A water-tight sealing of the plunger in the barrel is achieved by three rubber O rings held in grooves in the end of the plunger (Fig. 2-B). These O rings are changed after each sterilization to remove any danger of their perishing and consequent failure during use.

The end of the barrel is pierced by a small hole which is sufficiently large to allow easy filling and emptying of the syringe, but yet small enough to prevent escape of the contents of the syringe. The outside of the end of the barrel is provided with Sherman-type coarse screw threads which are fluted to provide a self-tapping action (Fig. 2-B). Therefore, the syringe, when screwed into a predrilled hole in the femoral head, cuts a female thread in the bone, avoiding the danger of compressing bone which would give a false picture of avascularity. The large syringe can deliver about 0.25 milliliter, and the small syringe about 0.1 milliliter.

The Injected Solution

Na^{24} was obtained from Oakridge National Laboratories and prepared with extra sodium chloride to give an isotonic solution in the Addison Gibson Laboratories under the direction of Campbell Moses, Jr. For the experimental work it was used at a strength of 1,000 microcuries per milliliter at first, but this was later reduced to fifty to sixty microcuries per milliliter for use in both animals and human beings. The large syringe is used partly filled to give a dose of between five and ten microcuries. The small syringe delivers a dose of less than five microcuries.

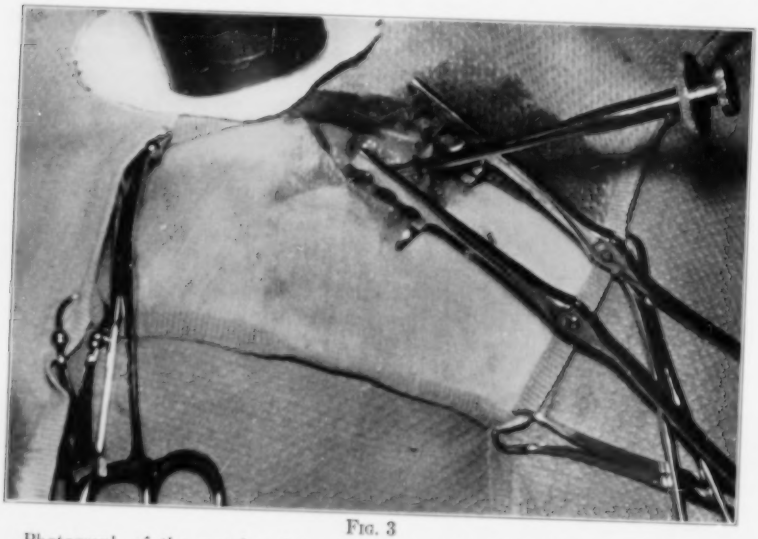

FIG. 3

Photograph of the metal syringe after its insertion into the predrilled hole in the neck and head of a dog's femur during a study in a live head. The procedure was performed by the blind method. The syringe can be seen passing into the wound between the jaws of the self-retaining retractor. The end of the columnated scintillation probe can be seen at the upper left. It is centered so that a reading may be taken from the femoral-head area.

Instruments for Counting the Radiation

The gamma photons emitted by the Na^{24} were counted with a scintillation probe containing a thorium-activated sodium-iodide crystal. In the first animal experiments, a crystal half an inch in diameter was used. For increased sensitivity, a two-inch crystal was used for the human subjects, which enabled a smaller dose of Na^{24} to be used. The probe is held in an adjustable mechanical arm for easy positioning, and is columnated by a lead column, preferably of the honeycomb type, to narrow the zone from which the counts are taken. The probe is connected to a rate meter, and the counts are recorded on a rectilinear riter; thus, a graph of the clearance was drawn by the stylus. In some cases, the counts were recorded on a scaler, and here an actual figure was obtained for each one of the ten minutes of counting by counting for a preset thirty seconds, then waiting thirty seconds, and then repeating the procedure. This latter method is most suitable for use in the operating room.

ANIMAL EXPERIMENTS

The purpose of the animal experiments was to test the method of radiosodium clearance by comparing the clearance from avascular and vascular femoral heads in dogs.

Procedure for Devascularized Femoral Heads

The study was carried out on twenty-two large, adult, mongrel dogs. The right hip of each dog was exposed under nembutal anesthesia and full aseptic technique. The femoral head was dislocated, the ligamentum teres was severed, and all vessels were stripped from the femoral neck. A hole was then drilled up the femoral neck from the lateral aspect of the shaft with a drill smaller in diameter than the threads on the end of the small syringe. The hole was extended well into the femoral head but not so far as the articular cartilage. The depth of the hole was carefully measured.

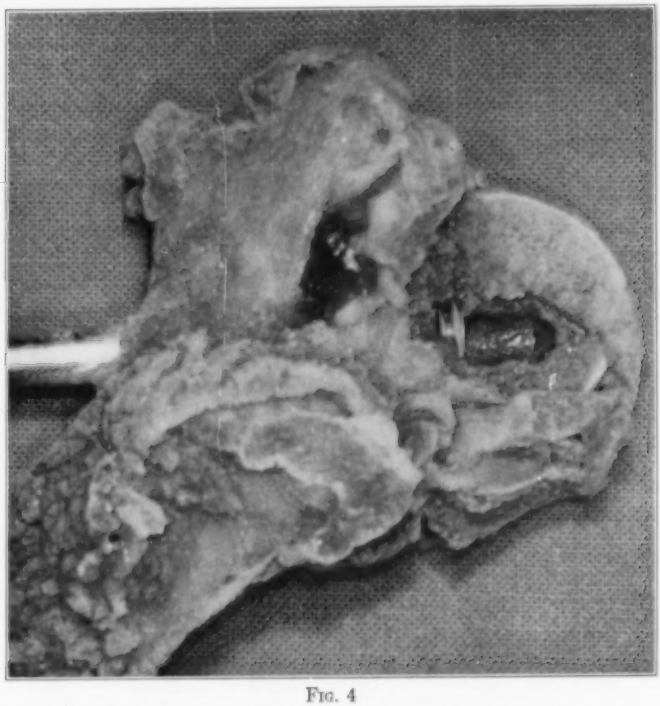

FIG. 4

Photograph of the upper end of the dog's femur after removal at autopsy. The drill hole inside the femoral head to the right was exposed by sawing the head in two. The syringe was then reinserted up the hole in the femur, passing from the lateral femoral cortex on the left to within about half an inch of the end of the hole on the right. The extreme tip of the syringe with its last two screw threads can be seen just entering the femoral head.

Technique of Loading the Syringe

The metal syringe was then loaded by assembling it, dipping its end into the radioactive saline solution, and unscrewing the plunger to aspirate the saline solution into the syringe. The outside of the syringe was then carefully washed in sterile water to remove all adherent radioactive solution. It was then held under the scintillation probe to determine if it was successfully loaded, which would be indicated by a high counting rate. Failure to fill satisfactorily was observed if the plunger had been unscrewed too rapidly or the syringe had been removed from the radioactive solution before it had had time to fill; the syringe was then refilled and tested again. The solution of Na^{24} used in the first experiments contained 1,000 microcuries per milliliter, but this was subsequently reduced to fifty to sixty microcuries. An isotonic and sterile solution was always prepared.

Method of Obtaining Clearance Rates

The metal syringe was inserted into the hole in the femoral neck (Fig. 3) and gently screwed in until its end was within about half an inch of the end of the hole (Fig. 4). The contents of the syringe were then emptied into the hole in the femoral head by screwing in the plunger completely. Care was taken to empty the syringe entirely.

The scintillation probe, held in an adjustable mechanical arm, was then swung over the femoral head and accurately centered. The rate meter was read on the logarithmic scale, and the approximate counts at a distance of about two

TABLE I

Na^{24} Clearance Studies in Femoral Heads of Dogs *

Experiment No.	Dog No.	Devascularized Head	Vascular Head	First Count per Minute	Second Count per Minute	Fall	Clearance (*Per cent*)
1	146	×		9500	9550	0	0
			×	7390	5450	1940	26.2
2	188	×		1420	1390	30	2
			×	15660	8260	7400	47
3	272		×	19000	12120	6880	36.2
4	273	×		12000	11400	600	5
			×	1550	1125	425	27.4
5	282	×		1921	1899	22	1
			×	5710	3840	1870	32.7
6	320	×		16500	16500	0	0
7	364	×		19300	19380	0	0
8	368	×		3121	3099	22	1
			×	3640	3894	3000	38.5
9	369	×		3550	3480	66	1.8
			×	9797	3127	1670	34.8
10	370	×		10039	9674	364	3.6
			×	8564	7274	1290	16.2
11	378	×		7790	7780	10	0
			×	5991	4770	1221	20.3
12	396	×		15940	16330	0	0
13	407	×		1136	973	163	14.3
14	413	×		5690	5700	0	0
			×	10979	9442	1537	13.9
15	414	×		12000	12500	Rise	0
			×	18500	15500	3000	16.2
16	480	×		13000	12750	250	2
			×	13000	10000	3000	23
17	512		×	10000	7500	2500	25
			×	19000	14000	5000	26.3
18	525	×		16500	16500	0	0

* This table gives the corrected counts per minute obtained over the femoral heads of dogs at the start and finish of each ten-minute clearance run. The difference between these two counts, if any, expressed as a percentage, is the clearance rate.

to three inches from the femoral head were obtained. The counts were taken on the most convenient scale, using either 5,000, 15,000, or 50,000 counts per minute as the top of the graph paper in the automatic recorder. Counting was continued for ten minutes. At the end of this time, the syringe was unscrewed from the bone and carefully wiped and washed free of external radioactivity. It was then placed under the scintillation counter at approximately the same tube-syringe distance as was used during the clearance run, and the residual activity in the syringe in counts per minute was determined. This count represented the Na^{24} not available for clearance during the run and it was subtracted from the counts per minute at the start of the run and also during the last minute of the run. The decay

of Na^{24} in six minutes is only 0.5 per cent; hence, this factor was ignored. The percentage fall in counts expressed as a percentage of the original activity over the femoral head was used as the Na^{24} clearance.

Procedure for Vascular Heads

Two weeks after the operation on the devascularized femoral head, the left hip of each dog was used to obtain the clearance from a vascular femoral head.

The lateral aspect of the upper femoral shaft was exposed. A hole was drilled up the femoral neck into the femoral head to the juxtachondral zone. The depth of the hole was carefully measured, and the loaded metal syringe was screwed in to within a half inch of the end of the hole. A clearance study was then run in the same manner as described for the devascularized heads, including a residual

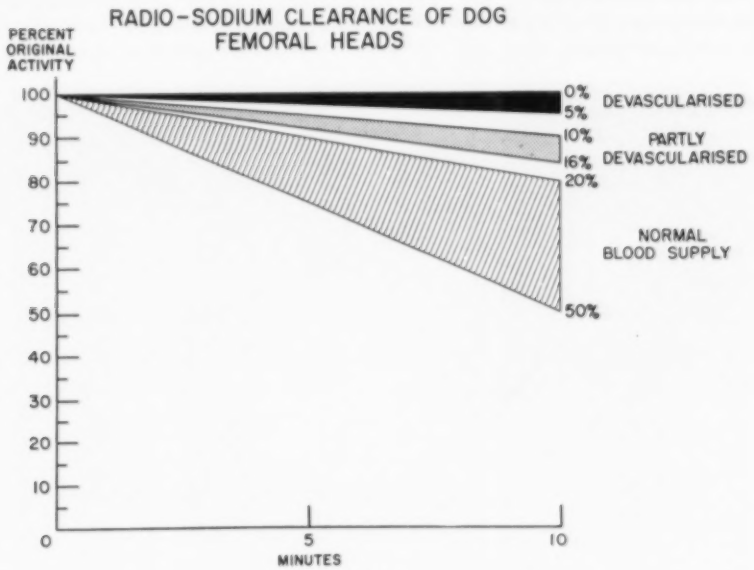

CHART I

Here are presented in diagrammatic form the results of the dog experiments. The fifteen devascularized femoral heads gave clearances below 5 per cent in ten minutes. Four partly devascularized heads gave clearance values of between 10 and 20 per cent. Eleven vascular heads gave clearances of from 20 to 50 per cent.

count over the syringe. By use of the corrected counts in the first and tenth minutes, the percentage fall or Na^{24} clearance was calculated as was done with the devascularized head.

At autopsy both femoral heads were removed. The blind drill holes were checked for location, and the results in those misplaced were discarded. Histological sections were prepared from all the femoral heads.

RESULTS

The results are recorded in Table I and presented in graphic form in Chart I. Thirty femoral heads suitable for study were obtained from twenty-two dogs. Wound infection, misplacement of the drill hole, and intercurrent disease made some hips unsuitable for study. Also, some of the earlier dogs were so small that the syringe could not be inserted into the femoral head.

The results could be classified into three groups as follows:

Group 1. In fifteen femoral heads the clearance rate in ten minutes was 5 per cent or less, indicating complete devascularization.

Group 2. In eleven femoral heads the clearance rates were between 20 and 50 per cent, indicating vascularization.

Group 3. In four femoral heads the rates were between 10 and 20 per cent, indicating partial devascularization.

The striking difference between the rapid clearance of the isotope from the vascular heads and its failure to move from all but one of the heads that had been devascularized is the essence of the experiment.

The femoral heads were studied histologically, and, in general, the clearance studies were confirmed in that the non-devascularized heads showed no areas of marrow death or empty lacunae. The devascularized heads showed varying amounts of bone necrosis with necrotic marrow cells and empty bone lacunae. However, very rapid bone repair takes place up the drill hole in the dog and confuses the histological picture. The gross changes in the femoral heads were, however, obvious (Fig. 5), as the cartilage on avascular heads was xanthochromic, pale, soft, and pitted.

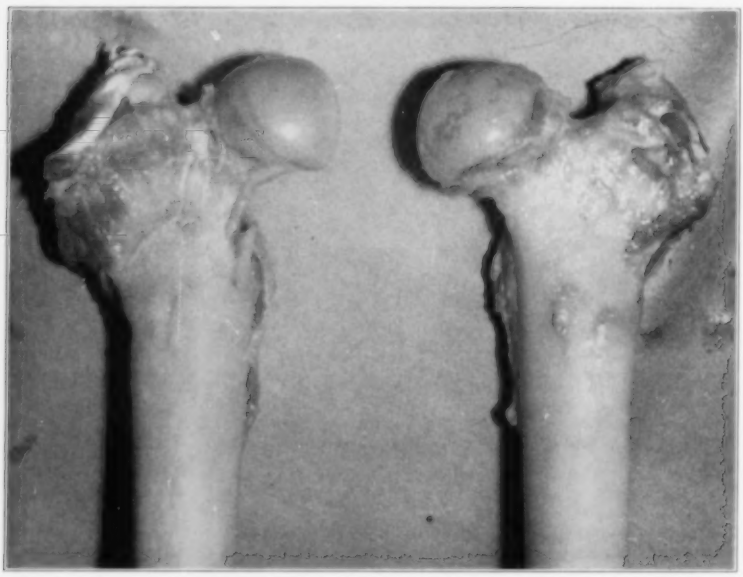

FIG. 5

Photograph of two femora removed at autopsy from one of the dogs. On the left is the normal-looking femoral head on which blind drilling and a sodium clearance study were done. On the right is the devascularized femoral head with pale, pitted articular cartilage.

The difficulty in interpreting the histological picture even in dogs is instructive. Sherman showed that areas of apparently dead bone may be demonstrated in the bones of older subjects with peripheral vascular diseases.

CLINICAL APPLICATION

It became obvious that Na^{24} clearance in dogs gave reproducible results. Avascular femoral heads gave 5 per cent clearance or less, and vascular heads gave 20 to 50 per cent clearance. Encouraged by these results and the ability to use doses of five to six microcuries of Na^{24}, we believed that clinical trial could be undertaken. Na^{24} clearance studies were then initiated on suitable cases of fractures of the femoral neck and dislocations and fracture-dislocations of the hip in adult human subjects. We studied nine cases of fractured femoral necks, five cases of dislocation or fracture-dislocation of the hip joint, and one case of spontaneous avascular necrosis of the femoral head.

Patients with obvious roentgenographic signs of avascular necrosis of the femoral head as well as patients with the fresh trauma were included. The dislocated hips provide the opportunity for a good long-term control of the procedure.

OPERATIVE PROCEDURE ON HUMAN SUBJECTS

The method of radiosodium clearance may be added to the usual roentgenographically controlled internal fixation of a fracture of the neck of the femur without unduly prolonging the operation. When investigating the circulation after dislocation of the hip, the whole procedure is much more simple. For this reason the technique used in a case of fracture of the femoral neck will be described.

The patient is anesthetized, and the fracture reduced. Two x-ray tubes are placed in position for anteroposterior and lateral views of the femoral neck. Two polaroid cassettes greatly speed the procedure. The scintillation probe, held in its mechanical arm, is positioned so that it can be swung over the hip joint when the time comes to count the radiation (Fig. 6). The probe is connected to a rate

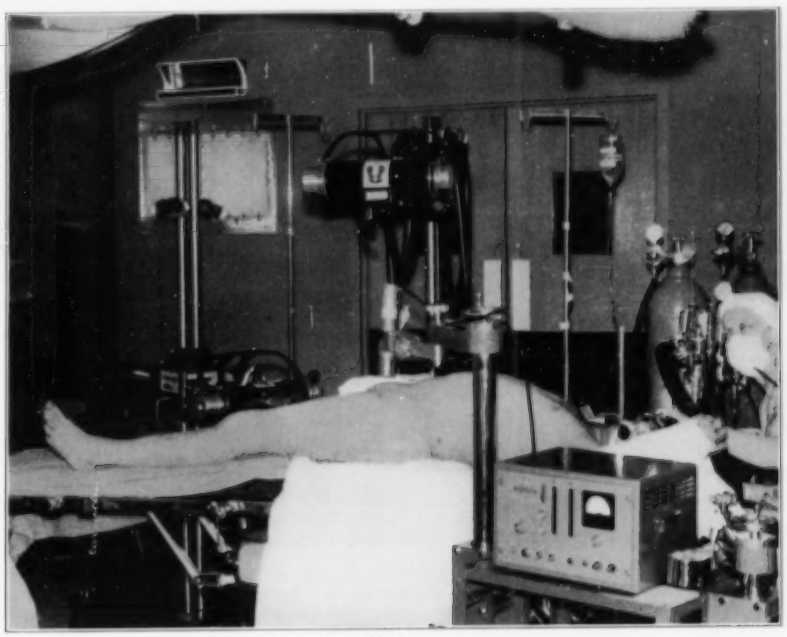

FIG. 6

An ordinary operating-room table is used. Two x-ray tubes are positioned for anteroposterior and lateral roentgenograms. The scintillation counter (over the patient) is held in a mechanical arm and connected to a scaler (right foreground).

meter and automatic recorder or to a multiscaler. After checking the reduction of the fracture, the lateral surface of the femur is exposed as if for blind nailing of the femoral neck. A small circular piece of the cortex is removed, and a guide wire is inserted up the femoral neck into the head. Care must be taken not to penetrate the articular cartilage or the Na^{24} will escape through it. If the wire enters the joint it must be left in position and another one inserted adjacent to it. A long cannulated drill is then passed up the guide wire well into the femoral head, but not so far as the cartilage (Fig. 7). When the position of the drill is satisfactory as shown by roentgenograms, it is removed along with the guide wire before insertion of the loaded large metal syringe which must penetrate to within a half inch of the end of the predrilled hole. The drill has the same outside diam-

eter as the barrel of the syringe so that when the syringe is screwed into the hole, the screw threads at the end of the barrel bite into the bone of the head, producing a water-tight seal.

The syringe is loaded in the same manner that was described for the animal experiments. The Na^{24} in sterile isotonic saline solution, fifty to sixty microcuries per milliliter, is placed with great care in a small beaker on a special table reserved for the radioactive material. All procedures should be quickly checked with a monitor counter to detect any contamination of gloves, floor, or drapes. The washed and dried syringe is held under the scintillation probe to confirm that it is loaded. If it is, then the rate of count rises dramatically. The syringe is then screwed up the predrilled hole in the femoral neck to within a half inch of the end (Fig. 9). This insertion must be performed very carefully since the guide wire and drill have been removed and nothing maintains the reduction of the fracture except the position of the limb. The syringe will find its own way in, and

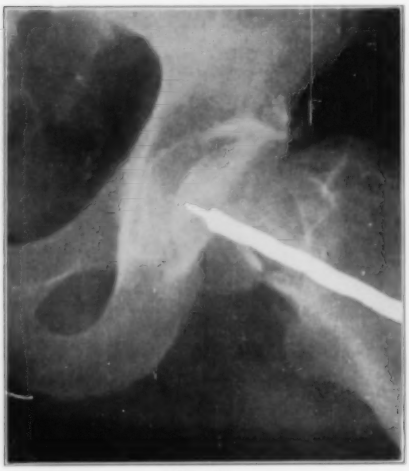

FIG. 7

FIG. 8

Fig. 7: Roentgenogram made during the performance of a radiosodium clearance study of a fracture of the femoral neck in a human adult. The fracture was reduced, a guide wire was inserted, and a cannulated drill, one-quarter-inch in diameter, was passed over the guide wire.

Fig. 8: Roentgenogram showing the next stage in the radiosodium clearance study. The drill and guide wire have been carefully withdrawn and the syringe, loaded with about five microcuries of Na^{24} in isotonic saline solution, is screwed into the bone until it reaches to within one-half inch of the end of the drilled hole. This remaining half inch forms the experimental chamber into which the drop of radioactive material is expressed. It can be dimly seen extending into the femoral head beyond the end of the syringe.

it is screwed home gently and firmly. If it is pushed in forcibly, it is conceivable that the femoral head might be rotated on the femoral neck. This complication has not yet been seen in this series. The position of the syringe is confirmed by roentgenograms; it should reach just across the fracture. The syringe is then emptied by screwing home the plunger completely, and must be done carefully to avoid dislodging the syringe. The dose delivered is about five to six microcuries in about 0.1 milliliter of solution. The scintillation probe is then swung over the anterior surface marking of the femoral head in the groin. Its distance is adjusted to give a suitable count, which is usually somewhere between 5,000 and 20,000 counts per minute. The actual count is not critical so long as it is at least ten times the background. Counts are taken on the scaler each minute for ten minutes. This may be done by counting for thirty seconds, waiting for thirty seconds, and then counting for another thirty seconds and continuing in this

manner for each minute. As an alternative method the probe may be connected to a rate meter, and this in turn may be connected to an automatic recorder, such as a rectilinear riter. The stylus records the variations in counts as the run proceeds and accurately reproduces the counts per minute. The needle can easily be watched by the surgeon for the striking difference between the falling needle of a good clearance and the steady needle when the head is avascular. At the end of the ten-minute run, the syringe is unscrewed from the bone. At this stage the escaping blood is slightly radioactive and is carefully collected on large swabs which are placed in waterproof bags for subsequent disposal. The syringe is thoroughly rinsed and wiped dry and then is placed on a table under the scintillation probe at the same tube-syringe distance as was used during the operation.

The count taken here provides information on whether or not the syringe emptied completely. Obviously, any Na^{24} that remains inside the syringe would not have been available for clearance by the circulation.

Calculation of the Clearance

The count per minute obtained over the syringe is subtracted from the count over the femoral head in the first minute and also from the count in the tenth minute. The corrected count in the tenth minute is subtracted from the count in the first minute, and the difference is expressed as a percentage of the count in the first minute and is the Na^{24} clearance for that case. This calculation is simple when a scaler is used, for an actual number can be read off the machine for each minute counted. When an automatic recorder is used, the graph paper must be removed from the machine for calculation to be made. This is more suitable for experimental purposes because an accurate record is provided.

FIG. 9

After a good radiosodium clearance of 35 per cent in ten minutes was obtained, a guide wire was reinserted, and a Smith-Petersen nail was inserted to hold the fracture reduced until union will occur.

Finish of the Operation

After calculation of the Na^{24} clearance in a fractured neck of the femur, a guide wire may be reinserted. This is easily accomplished by, first, partly reinserting the cannulated drill that was used to make the experimental chamber in the head of the femur. The guide wire can then be passed up the cannulated drill, and the drill withdrawn. Nailing of the fracture is completed in the usual manner. If the surgeon elects to remove the femoral head and insert a prosthesis, he can extend the incision anterosuperiorly, using the Watson-Jones approach.

SAFETY OF THE METHOD

The method described was monitored by Mr. Herman Cember and Mr. Mortimer Heller of the Graduate School of Public Health, University of Pittsburgh. The dose of five to six microcuries of Na^{24} is considered very small. Direct-reading dosimeters worn by the surgeon and the team showed a maximum dose of less than five microrads per hour received from the Na^{24} during the operation. On the other hand, up to fifty-five microrads was received by one of us (P.G.L.) during blind nailing of a fractured femoral neck; the vast majority

of the fifty-five microrads came from roentgen-ray radiation. Film badges should, of course, be worn any time that roentgen rays or radioisotopes are used. No overdosage was detected on the badges in the procedure outlined. The dose to the patient is minute, because any Na^{24} not quickly excreted in the urine decays rapidly (half-life, 15.06 hours).

Drapes and sponges contaminated during the operation seldom show more than two or three times the background count. The more heavily contaminated materials, however, can be stored for three or four days, after which time nearly all radioactivity will have disappeared.

DISCUSSION

From the animal experiments and from our preliminary experience in human beings, it appears that radiosodium clearance studies offer a method of determining bone vascularity. The method is simple and is advantageous because it is fairly certain that the femoral head is avascular if no clearance occurs. Leakage of the injected radioactive material might lead to a false clearance, but in this case the surgeon would proceed to simple internal fixation. By careful technique it is possible, however, to avoid such leakage in most cases.

The placing of the experimental chamber is also open to debate. If a nail is to be inserted along the same track as the syringe, then the chamber should probably be in the posteroinferior portion of the head. However, a test of Na^{24} clearance of the superior portion of the head may be of more value prognostically.

In the case of dislocation of the hip joint and spontaneous avascular necrosis of the femoral head there is no objection to performing the clearance study in the superior portion of the head.

It is difficult to obtain controls in studies on human beings. However, Na^{24} clearance studies have been performed on two cases of roentgenographically obvious aseptic necrosis of the femoral head. In both cases, clearances of 0 per cent were obtained.

Full evaluation of the method must obviously await long-term follow-up studies.

NOTE: We wish to express our thanks to Dr. Campbell Moses, Jr., under whose A.E.C. license this work was performed, to Dr. Paul M. Meadows, Assistant Professor of Radiology, University of Pittsburgh, C. M. Williams, M.D., Ph.D., Mr. Herman Cember, Radiological Safety Officer, and Mr. Mortimer Heller, Health Physicist, Graduate School of Public Health, University of Pittsburgh, for help and advice, to Mrs. Mary Grebner, Miss Patricia Orlic, and Mr. Joseph Sunder for technical assistance.

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DISCUSSION

Dr. Harold B. Boyd, Memphis, Tennessee: Several research workers are applying various methods to determine the viability of the head of the femur after trauma. All methods have advantages and disadvantages. We must not lose sight of the fact that we are trying to devise a test and that none of us yet know the accuracy of any of these tests. Dr. Laing and Dr. Ferguson have presented a method of using the sodium clearance test. My associates and I have been working with the accumulation of the P^{32} in the head of the femur, as reported in *The Journal of Bone and Joint Surgery* in 1955. With the use of P^{32} we are able to obtain counts from a small, well circumscribed area, with minimum damage to the head of the femur. The impairment of the circulation varies in different portions of the head, so we now prefer to obtain counts from the weight-bearing portion—that is, the area in which collapse of the head occurs clinically after avascular necrosis. With the P^{32} method, the radioactive material is delivered to the bone primarily through the arterial circulation, whereas the clearance curve of sodium depends primarily on venous drainage. One of the illustrations shown by the authors revealed a rather large defect in the central portion of the head of the femur which extends on both sides of the epiphyseal scar and should allow disappearance of sodium if the venous return is patent from any part of the two circulatory systems in the head of the femur. By use of the P^{32} method, we have noted more radioactivity in the lower portion of the head of the femur than in the upper weight-bearing area. Therefore, a localized count in the weight-bearing area should be preferable. This is armchair theorizing, and one should hurry back to the basic principle that we are developing a test and that whether or not that test is valid will depend on follow-up study. It will be necessary for the authors to follow a series of patients over at least a two-year period to determine the validity of their test. I cannot agree with their statements that the surgeon does not have to wait for collapse of the femoral head to indicate the presence of avascular necrosis, but that he can tell immediately after the injury what the state of vascularity of the head is and, if it is avascular, can take active steps to encourage reinvasion of the head by blood vessels by whatever procedure he favors. Any procedure that the surgeon employs will alter the blood supply, and I assume that this might also include the removal of the head of the femur for the insertion of a prosthesis in those patients in whom the presumptive diagnosis of avascular necrosis had been made. Such a procedure would remove all chance of determining whether the test was valid. This is too naive an approach to withstand scientific scrutiny, and would be looked on with skepticism by a sophisticated research worker.

At the present time, with the P^{32} method, we have data on 167 patients with fresh fractures of the neck of the femur. Of these, seventy have been followed for two or more years. At present, the data appear favorable. However, we do not plan to use the test clinically until we have correlated our experimental data with the clinical end results in at least 100 cases.

I should like to encourage the authors to do the same, so that we can compare the degree of confidence in the sodium clearance curve with the P^{32} accumulation method to determine the viability of the head of the femur.

Dr. Ferguson (closing): Although there are certain areas in which we disagree with Dr. Boyd, we do not disagree about the fact that this is a preliminary report and that we must be very cautious in drawing any conclusions as to the clinical value of this test. As a matter of fact, we have used the method for the most part in cases where the condition of the blood supply to the femoral head was reasonably well known in order to test the accuracy of the method. For example, we have used it in cases in which we knew the head was dead.

I should like to emphasize that there is a great difference in the behavior of P^{32} and Na^{24}. The uptake of P^{32} is a measure of the vascularity of the bone, if indeed it is a measure of vascularity at all. Its uptake is also a measure of the amount of soft tissue within the bone. The clearance of Na^{24} is also dependent on the vascularity and the soft-tissue content of the bone, but the amount of sodium used is so small that the error caused by the presence of sodium and sodium exchange in the soft tissues does not affect the results of this test materially. By use of clearance as opposed to uptake there are certain safeguards which are built into this method. We would like to emphasize the value of the clearance method more than the use of sodium. We feel that there can be no quarrel with the results in the case where no clearance of sodium is observed. Certainly, it is easy to establish the fact that the syringe has been emptied. If no sodium clearance is found at the time of surgery there would seem to be a good deal of justification for not using conventional methods of internal fixation. It is in the cases when the clearance rates are intermediate that one might question the value of this test.

In closing, I should like to re-emphasize that the importance of this study is the application of the clearance method rather than the use of sodium. Using exactly the same method on twenty-eight hips in twenty-three dogs we have obtained similar results with sharper definition.

Treatment of Comminuted Fractures of the Calcaneus by Primary Triple Arthrodesis*

BY KEARNS R. THOMPSON, M.D., AND CARL M. FRIESEN, M.D.,
LEXINGTON, KENTUCKY

There are many varieties of fractures of the calcaneus, but comminuted fractures are frequent and produce the greatest disability. In the treatment of these fractures there is much difference of opinion and general pessimism as to the outcome. One of us (K.R.T.) began treating these fractures by primary triple arthrodesis in 1948, and it has been our experience that this procedure produces a high percentage of satisfactory results.

ANATOMY

The calcaneus, which is the largest bone in the foot, articulates superiorly with the talus and anteriorly with the cuboid. There are three superior articular surfaces: the posterior, the middle, and the anterior (Fig. 1-A). The posterior articular surface is dome shaped, is inclined obliquely forward at approximately 45 degrees to the long axis of the body, and is the largest of these articular areas. The elongated medial articular surface is usually divided into two parts by a notch. The area posterior to the notch and lying anterior to the posterior articular surface is the middle articular surface; it is supported by the sustentaculum tali. The area anterior to the posterior articular surface and lateral to the middle articular surface is the calcaneal sulcus; it forms the inferior half of the sinus tarsi. The posterior portion of the calcaneus is the tuberosity, whereas the anterior projection forms the cuboid articular surface. Superior and medial to the cuboid articular surface, a bone prominence is evident, which is called the anterior process.

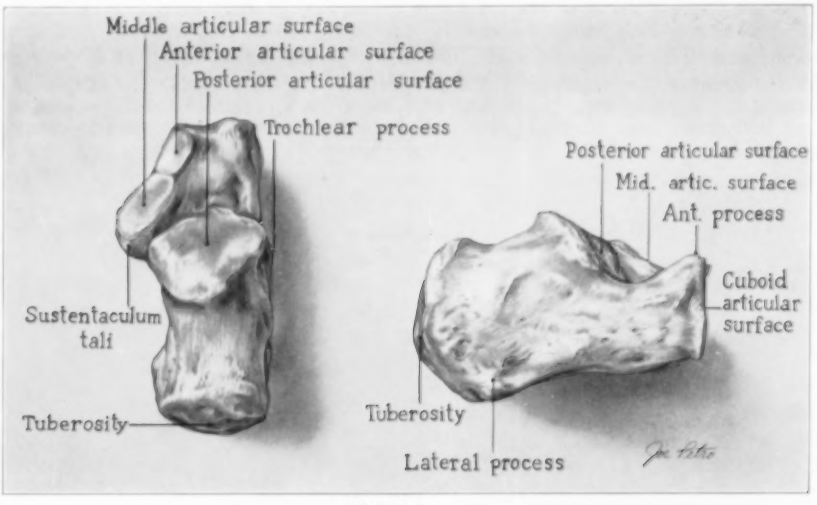

FIG. 1-A

Superior and lateral projections of the calcaneus.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 27, 1959.

FIG. 1-B

Inferior projection of the calcaneus.

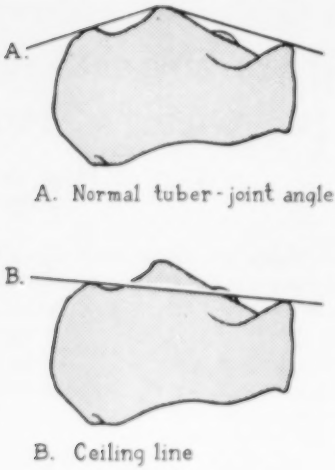

FIG. 2

Drawing of the ceiling line.

The cuboid articular surface is concave from above downward and lateralward and convex in a direction at right angles to this. As has been pointed out by Shephard, the configurations of the articular surfaces of the calcaneocuboid joint, of the ball-and-socket talonavicular joint, and of the subtalar joint allow medial and lateral motions of the foot. The calcaneus, when visualized from below (Fig. 1-B), exhibits a lateral bowing, or convexity, and a medial concavity.

ROENTGENOGRAPHIC EVALUATION

As far back as 1720 (according to Goff), Garangeot described the "smashed fracture". With the discovery of roentgen rays in 1895, Desfosses offered the first accurate interpretation of the fractured calcaneus. In 1908 Cotton and Wilson described their manipulative technique for treatment of this fracture, based on roentgenographic interpretation. Most investigators during the past fifty years have recommended that the roentgenographic diagnostic survey of a patient with a painful heel after injury should include an anteroposterior projection of

FIG. 3

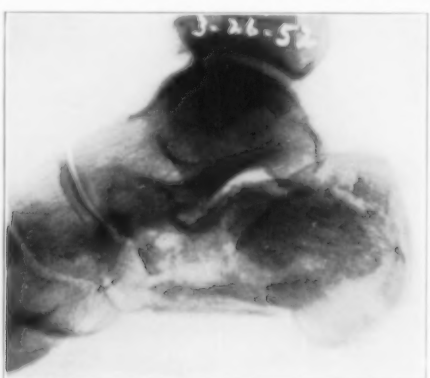

FIG. 4

Fig. 3: Anteroposterior roentgenogram of the ankle, showing fracture of the calcaneus, with lateral spread.

Fig. 4: Case 3 (Table II). Lateral roentgenogram of the calcaneus, showing a comminuted fracture of the entire body, involving the subtalar and calcaneocuboid joints.

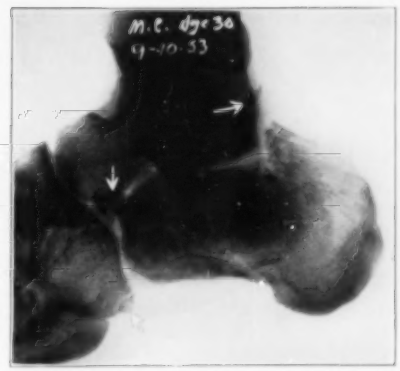

Fig. 5-A

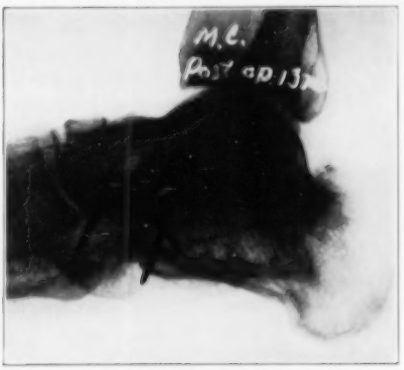

Fig. 5-B

Fig. 5-A: Case 9 (Table I). Lateral roentgenogram of the calcaneus, showing a severe depression fracture of the posterior articular surface as well as the anterosuperior articular surface, with avulsion fractures of the posterior aspect of the talus and of the cuboid.

Fig. 5-B: Case 9 (Table I). Postoperative lateral roentgenogram after triple arthrodesis in which two staples were utilized for internal fixation, showing restoration of the trabecular pattern across the arthrodesed joints.

the ankle, a lateral projection of the ankle and calcaneus, and an axial (plantar) projection of the calcaneus. From our experience we believe that two additional, although previously described, projections are necessary: a lateral-oblique projection of the calcaneus and an anteroposterior projection of the mid-tarsal joints.

In the anteroposterior projection of the ankle joint, injuries of the ankle, as well as lateral spreading of the calcaneus (Fig. 3), can be detected. In addition to visualizing the fracture lines, the lateral projection permits the evaluation of the tuber-joint angle of Böhler (Figs. 4, 5-A, and 6-A), as well as the "ceiling line" described by G. E. Wilson (Fig. 2). This line joins the anterosuperior with the posterosuperior angle of the calcaneus. Lateral roentgenographic interpretation, as was pointed out by G. E. Wilson in 1950, is also dependent on the position of the foot at the time that the roentgenogram is made; that is, whether the foot is inverted or everted. An axial (plantar) projection shows the medial malleolus, the lateral malleolus, the base of the fifth metatarsal, medial concave and lateral convex surfaces, the fractured sustentaculum tali (Fig. 6-B), and fracture of the posterior articular surface (Fig. 7).

The two additional projections used by us show involvement of the articular surface of the calcaneus at the calcaneocuboid joint, which is not evident in the conventional lateral projection. The lateral-oblique projection visualizes fractures involving this articular surface (Figs. 6-C and 6-D), as well as fractures involving the anterior process, whereas the anteroposterior projection of the mid-tarsal joints shows fractures involving the articular surface of the calcaneus at the calcaneocuboid joint, which frequently are associated with a lateral spreading displacement of the lateral cortex at the joint (Fig. 8-B). As has been pointed out by Conn, depression of the articular surface and joint incongruity are also present. In the more severe fractures, medial subluxation of the talus at the talonavicular joint takes place (Fig. 9). There has been lack of emphasis on the importance of these two projections which portray fractures involving the anterior articular surface as well as any abnormality in the talonavicular joint. We believe that some of the unsatisfactory results encountered in the past with treatment other than triple arthrodesis are because of the lack of recognition of the associated injuries involving the two peritalar joints. Proper evaluation of the extent of the comminuted displaced fractures is only possible on the basis of these five roentgenographic projections.

CLASSIFICATION

In 1952 Essex-Lopresti presented a classification of calcaneal fractures:

Group 1: Not involving subtalar ("subtaloid") joint
- A. Tuberosity fractures
  1. Beak type (Boyer)
  2. Avulsion of medial border
  3. Vertical
  4. Horizontal
- B. Involving calcaneocuboid joint
  1. Parrot-nose type
  2. Various

Group 2: Involving subtalar ("subtaloid") joint
- A. Without displacement
- B. Tongue type, with displacement
- C. Centrolateral depression of joint
- D. Sustentaculum tali fracture alone
- E. With gross comminution
  1. From below (including severe tongue and joint-depression types)
  2. From behind forward, with dislocation, subtalar ("subtaloid") joint

This paper considers only those fractures of the second group, with displacement and involvement of the subtalar joint. In B (tongue type with displacement), C (centrolateral depression of the joint), as well as E (with gross comminution), decreased tuber-joint angle, comminution, and deformity are exhibited. We found that these fractures exhibit, in addition, extension forward of the fracture into the cuboid articular surface, with lateral spreading. Also common, and evident in the more severely comminuted fractures, is subluxation of the talar head at the talonavicular joint. Fracture of the cuboid articular surface of the calcaneus should always be considered as an aspect of comminuted fractures of this bone because of its usual occurrence and the disability it produces. We believe that the fracturing force bows the lateral cortex of the calcaneus like a barrel stave, producing the lateral spread of the bone and the extension of the fracture into the articular surface at the calcaneocuboid joint (Fig. 10).

REVIEW OF TREATMENT

In 1938 Goff presented a comprehensive review of the literature which included 151 references. The disability produced by comminuted fracture of the calcaneus was recognized early, and in 1912 van Stockum reported open reduction with subtalar arthrodesis. Magnuson drew attention to the upward displacement of the posterior fragment and, in 1917, recommended subcutaneous tenotomy of the Achilles tendon to eliminate this upward pull, combined with manipulation to break up the impaction and force the heel downward. He immobilized the foot in a plaster cast in a position of strong inversion and equinus. In 1923 he was the first to recognize the lateral piling up of bone beneath the external malleolus and recommended removing this mass and creating a trough for the peroneal tendons. This was followed by manipulation of the calcaneus, shifting it medially with the use of a wrench if the subtalar joint was not ankylosed and if manipulation was possible. Cotton also called attention to the disabling aspects of the piling up laterally, as did Cabot and Binney.

With continued dissatisfaction with results obtained from closed manipulative procedures, attention was focused on surgical management. In 1927 P. D. Wilson pointed to the contributions of Conn, Allison, and Reich, who, in 1926, recommended arthrodesis of the subtalar joint. He reported twenty-six patients on whom he did twenty-eight subtalar arthrodeses. In his experience, early operation—that is, on patients with recent fractures—gave the best results, with an

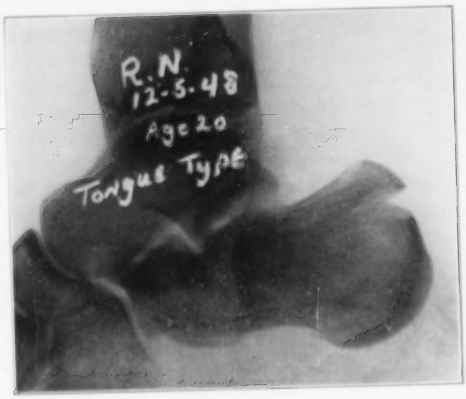

FIG. 6-A

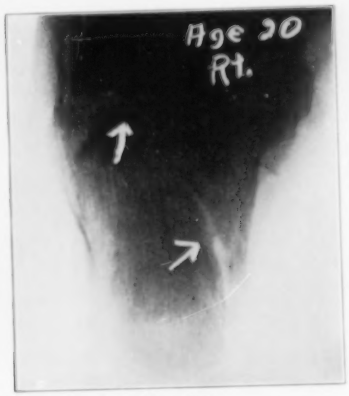

FIG. 6-B

Fig. 6-A: Case 1 (Table II). Lateral roentgenogram of the calcaneus, showing a tongue-type fracture.

Fig. 6-B: Axial (plantar) roentgenogram of the calcaneus, showing a fracture of the sustentaculum tali.

FIG. 6-C

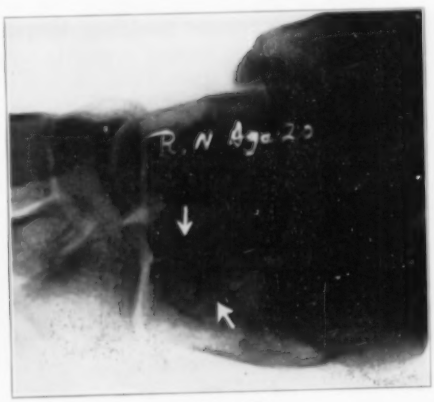

FIG. 6-D

Fig. 6-C: Photograph showing the positioning for the lateral-oblique view, to show fracture involvement of the calcaneocuboid joint.

Fig. 6-D: Lateral-oblique roentgenogram of the calcaneus, showing the fracture extending into the cuboid articular surface.

average disability period of five and one-half months. Old fractures treated by this method did less well, with an average disability period of eight months. Wilson also performed an arthrodesis of the talonavicular joint in some instances, and found that results seemed to be improved by this addition. He was among the first to mention that occasionally the calcaneocuboid articulation is involved by the fracture. It is believed that his detection is of key importance, and one which has gone unrecognized by many subsequent investigators of the comminuted fracture. To further cite Wilson, he believed that a foot is better, solidly fused in a position of optimum function, than with limited motion, unfused and painful. He believed that there is no great amount of remaining motion, regardless of treatment.

In the following decade the pendulum swung back, and closed treatment came into vogue again. In 1931 Böhler described his method, in which he utilized skeletal fixation with Steinmann pins in the tuberosity of the calcaneus and in the lower tibia. The significant feature of this method was the attempt to achieve an accurate reduction using the tuber-joint angle as a guide. This angle, which he

FIG. 7

Axial (plantar) roentgenogram of the calcaneus, showing the fracture of the posterior articular surface.

described, is formed by the intersection of a line drawn along the upper contour of the tuberosity and a line uniting the highest point of the anterior process with the highest point of the posterior articular surface. This angle is usually 30 to 35 degrees. Böhler emphasized the significance of this angle in the diagnosis and reduction of fractures of the calcaneus, but when he used it as a guide to reduction he did not take into consideration the fact that even though the angle is restored, the joint surfaces may not be returned to normal nor may comminuted fragments be realigned. Böhler reported the use of this method of treatment in 100 cases but he did not give end-result statistics. This method was somewhat uniformly adopted, with efforts directed to techniques to restore the contour of the calcaneus.

Conn, in 1935, was among the first to appreciate the extent of these fractures as well as to anticipate disability. He found 85 per cent of fractures of the calcaneus to be of the smashed type. He pointed out, in his anatomical description, that frequently the sustentaculum tali is depressed and the subtalar joint disrupted. He also noted that the talonavicular joint is often subluxated and that the fracture involves the calcaneocuboid joint. He emphasized that, with these alterations in joint alignment and the resultant disturbance of the normal weight-bearing thrusts, the reason for both the pain and the failure of simple subtalar fusion is quite evident. He proposed a two-stage method of treatment. First, the impaction was broken up by using a heavy wooden clevis, and the fracture was immobilized by a modification of the Böhler technique. In the second stage, five weeks later, a triple arthrodesis was performed. He reported on nineteen fresh fractures treated by this method, with excellent results in all but two. Triple arthrodesis on six old fractures gave five good results.

Other modifications of the original Cotton procedure were described by Hermann in 1937 and by Goff in 1938. In 1943 Gallie reported his operative procedure of subtalar-joint fusion for which he used a posterior approach. He

FIG. 8-A

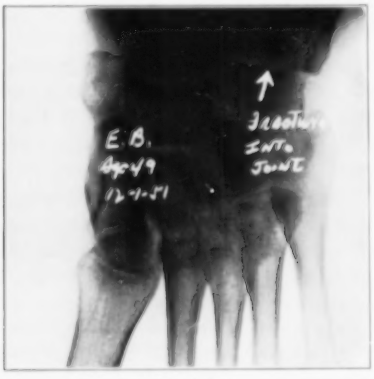

FIG. 8-B

Fig. 8-A: Photograph showing positioning for the anteroposterior view of the mid-tarsals for visualization of the talonavicular and calcaneocuboid joints.

Fig. 8-B: Anteroposterior roentgenogram of the mid-tarsal joint, showing the fracture extending into the calcaneocuboid joint, with lateral spread.

FIG. 9

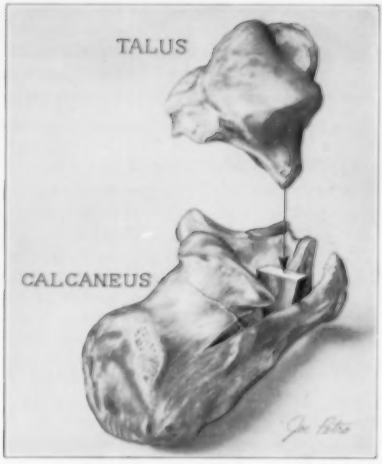

FIG. 10

Fig. 9: Anteroposterior roentgenogram of the mid-tarsal joint, showing the fracture extending into the calcaneocuboid joint and subluxation of the head of the talus (compare with Fig. 8-B).

Fig. 10: Drawing of the authors' conception of the mechanism of fracture involvement of the cuboid articular surface.

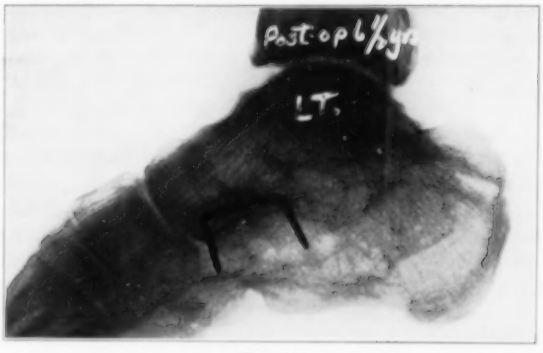

FIG. 11

Case 5 (Table I). Lateral roentgenogram of a triple arthrodesis, six and one-half years after operation, showing the staple transfixing the calcaneocuboid joint.

listed varus of the heel or other deformities as contra-indications. Harris, in 1946, recommended a three-pin type of traction, which he labeled tri-radiate traction, in which he used a ring with screw adjustments. Ten days after reduction he did a posterior subtalar fusion of the Gallie type through a window in the plaster and removed plaster and pins eight weeks later. He also recommended utilization of a Steinmann pin driven into the heel to pry up the depressed fractures; this was also recommended later by Gissane. Geckeler and Dick each reported his results of treatment by subtalar arthrodesis; Dick used grafts of cancellous bone, either homogenous from the bone bank or autogenous from the iliac crest. Of the nine patients he reported, all showed sound fusions and returned to work within an average period of six and one-half months. In 1946 Pridie described excision of the calcaneus in the treatment of these severe fractures. He believed that this was indicated because of the disruption of the subtalar joint with the resultant stiffness, pain, and disability which usually follow this type of fracture.

TABLE I

COMMINUTED FRACTURES OF THE CALCANEUS TREATED BY PRIMARY TRIPLE ARTHRODESIS IN PATIENTS WITHOUT ASSOCIATED INJURY

Patient	Age (*Years*)	Sex	Side	Occupation	Roentgenographic Healing (*Months*)	Back to Work after Surgery (*Months*)	Result‡	Length of Follow-up (*Years*)
1	58*	M	R	Farmer	5	6	E	2
2	36	M	L	Teacher	3.3	4	E	7.7
3	43*	M	L	Tobacco laborer	3	6	E	7
4	49*	M	L	Construction worker	3.5	6	G	1
5	55†	M	R	Roofer	3	7	E	6.5
			L		3	7	E	6.5
6	37*	M	R	Mover	4	7	E	1
7	49	M	R	Truck driver	3	6	E	3.3
8	45*†	M	R	Exercise boy	3	6	E	5
9	30	M	L	Farmer	3	7	E	1
10	35*†	M	R	Farmer	3	4.5	E	4.5
11	35*	M	R	Tobacco worker	3	5	G	.5
12	47*	M	L	Lumber worker	3	4	E	1.5
13	30*	M	R	Laborer	3	5	E	1.3
14	60*	M	R	Mason	3	5	E	.7
15	39*	M	R	Farmer	4	5	E	1.5
16	28*	M	R	Tobacco laborer	3	4	E	2.3
17	49	M	R	Contractor	4	11	F	2.5
18	49	M	L	Carpenter	2.5	11	G	1.8
19	56	M	L	Electrician	3	5	E	8.5
	Averages:				3.3	6.0		3.1

*Compensable cases.
†Bilateral fracture.
‡E = excellent; G = good; F = fair.

The results in two of the fifteen cases he reported were not satisfactory, and amputation was necessary in one.

In 1948 Palmer described open reduction and elevation of the depressed fragment of the posterior articular surface after a transfixion wire was placed in the tuber calcanei in order to apply downward and backward traction. The cavity left by elevating the fragment was filled with a graft of cancellous bone from the ilium. Essex-Lopresti, in 1952, described open reduction, pointing out that in 1902 Morestin first advocated open reduction. Open reduction was also described later by Leriche in 1913, by Lenormant, Wilmoth, and Lecoeur in 1928, and by Bérard and Mallet-Guy in 1929, as well as by Simon and Stultz in 1931. In the procedure described by Essex-Lopresti a graft was not used in the early cases since it was found that the cavity filled with cancellous bone and was not visible roentgenographically after eight weeks. However, if the operation was not performed within two weeks of injury, there was the likelihood that the cavity would not fill with new bone. In 1955 Allan and Maxfield and McDermott reported their experiences with open reduction and bone-grafting, using the technique described by Palmer. Whittaker, in 1947, described open reduction through a medial approach done on three patients; his eight-year follow-up was reported in 1954. In 1957, Thompson and Hughes and Leonard recorded their results after open reduction and grafting. Leonard used homogenous bone in order to avoid disability at the donor site.

RATIONALE AND INDICATIONS FOR TRIPLE ARTHRODESIS

From the literature it would appear that comminuted, displaced, calcaneal fractures cannot be successfully treated by closed manipulative procedures. Essex-Lopresti defined the comminuted fracture as one which has a primary fracture line which involves the body anterior to the posterior articular surface and a

TABLE II

COMMINUTED FRACTURES OF THE CALCANEUS TREATED BY PRIMARY TRIPLE ARTHRODESIS IN PATIENTS WITH ASSOCIATED INJURY

Patient	Age (*Years*)	Sex	Side	Occupation	Roentgenographic Healing (*Months*)	Back to Work after Surgery (*Months*)	Result†	Length of Follow-up (*Years*)
1	20	M	R	Student	3	4	E	5.5
2	32*	M	R	Riveter	3.5	7	E	9
3	44*	M	R	Carpenter	3	8	E	6.7
4	21	F	R	Housewife	2.5	9	E	4.5
5	30	M	L	Druggist	3.5	11	E	4.7
6	59*	M	L	Carpenter	3	10	E	6.3
	Averages:				3.1	8.2		6.1

*Compensable cases. †E = excellent; G = good; F = fair.

secondary fracture line which traverses the body just behind the joint. The fragment outlined by these fracture lines includes the lateral half or lateral two-thirds of the posterior articular surface. When displacement occurs this fragment is driven downward while the tuberosity is driven upward. The primary fracture line opens inferiorly, and there is associated widening of the body of the calcaneus due to lateral displacement of the fragments. In addition, as demonstrated in our cases, another fracture line extends forward on the lateral side into the articular surface at the calcaneocuboid joint.

In the past, arthrodesis of the involved joints has been recommended by various investigators on the assumption that irreparable damage to the articular surfaces has occurred and that aseptic necrosis of some of the fragments and arthritic changes will supervene. A one-joint or subtalar fusion was recommended at first. Then a two-joint arthrodesis including the subtalar and talonavicular joints was recommended by Wilson in 1927. Finally, a three-joint or triple arthrodesis was advocated in 1935 by Conn and subsequently by Geckeler who emphasized the importance of doing a triple arthrodesis when the calcaneocuboid joint was involved. With the realization that the calcaneocuboid joint is frequently involved it is our feeling that more surgeons will want to recommend triple arthrodesis.

By appropriate roentgenographic technique we have been able to identify the comminuted displaced fractures which disrupt the subtalar joint and involve the cuboid articular surface of the calcaneus at the calcaneocuboid joint as well as cause alteration of the tuber-joint angle and lateral spreading. Patients with these fractures have been selected, irrespective of their age, for primary triple arthrodesis. Twenty-five patients with twenty-six fractures treated by this technique are reported in this study.

PREOPERATIVE CARE

Care before surgery varied, depending primarily on the general condition of the patient and on the interval between injury and examination. Surgery was undertaken promptly before there was marked swelling if the patient was seen early. When the patient was not seen early, and when swelling was significant, general supportive measures were used until the local skin condition was believed to be satisfactory for operation. In some instances it was necessary to wait for edema blisters to heal, particularly when the fracture was severe and the patient had not been referred for treatment until several days after injury. In six instances, operation was delayed because associated injuries did not permit early surgery.

SURGERY

Surgery, in all cases, consisted in primary triple arthrodesis (talocalcaneal, talonavicular, and calcaneocuboid). In no instance was there an attempt to reduce

or improve fracture alignment by closed procedures. The operation is performed, using tourniquet control, with the patient inclined to the opposite side. The hip and knee are flexed approximately 30 to 40 degrees; the leg, ankle, and inner foot are placed on a sandbag so that the heel extends over the edge into varus position. The skin incision is of an Ollier type, which extends from the region of the lateral border of the extensor tendon near the talonavicular joint, transecting the sinus tarsi and continuing posterior to an area an inch inferior to the external malleolus. The skin is reflected with the underlying soft tissue and should not be undermined. The origin of the short extensor muscle is then reflected distally, and the sinus tarsi is entered. The dissection is extended to expose the calcaneocuboid joint, the talonavicular joint, and the talocalcaneal joint. The extent of the fracture of the calcaneus is then observed.

In each instance an attempt was made to accurately tabulate the findings at surgery, with particular reference to the fracture of the cuboid articular surface and of the subtalar joint. In some instances the peroneal tendon sheath was opened and the tendon reflected, in order to better expose and visualize the extent of the fracture. Frequently, the anterior process of the calcaneus was fractured and displaced. Whether fractured or not, it is removed, and the calcaneocuboid joint is resected. The capsule of the talonavicular joint is opened, and exposure is facilitated by stripping the capsule on its medial aspect with a Hatt spoon. This joint is then removed, and the subtalar joint is excised. This can be facilitated by removing the anterior margin of the posterior calcaneal articular surface of the talus which projects downward and anteriorly and somewhat obscures the joint. The cartilaginous surface of the talus is first removed, affording better visualization of the articular surface of the calcaneus and its comminuted pieces. Small, loose fragments are removed, and their articular surfaces are denuded before they are replaced. The depressed articular surfaces are elevated by means of an osteotome, which is placed between or beneath them. Manual lateral and medial compression helps to stabilize their position. Control of the fragments temporarily can be secured by means of a Kirschner or threaded wire introduced through the lateral cortex to facilitate denuding of the articular area. Removal of the cartilage from the middle articular surface is facilitated by means of stabilization with a pin inserted from the medial aspect of the foot. General reduction and apposition of the denuded surfaces are accomplished under direct vision. In most instances a staple is used to secure the calcaneocuboid joint (Fig. 11). The lateral fragment is manually compressed to eliminate any lateral piling up. A Kirschner wire is then inserted through the heel pad into the lateral fragment or cortex to prevent recurrence of lateral spread and to secure it soundly to the talus. In some instances a second staple has been placed from the lateral border of the calcaneus into the talus to prevent recurrence of lateral displacement (Fig. 5-B). Pin fixation has been utilized, as deemed necessary, to properly secure apposition of the denuded surfaces, as Caldwell recommends for triple arthrodesis. Occasionally, a second wire has been placed through the heel pad into the medial fragment of the calcaneus to secure it when there has persisted a tendency for it to be displaced. It has been found that contact, alignment, and stability are accomplished by the use of staples and Kirschner wires or pins. The extensor-muscle origins are replaced, and soft tissue is reapproximated. A leg plaster cast is applied, incorporating the plantar wires or pins, and the tourniquet is then released.

POSTOPERATIVE MANAGEMENT

The care after surgery is as usual for a triple arthrodesis, including proper elevation of the leg. The degree of comfort encountered, after the first twenty-four to forty-eight hours, in patients who undergo triple arthrodesis early is surprising when compared with that in patients whose associated injury necessitates delay. The patient is usually allowed up in a wheel chair on the third or fourth postoperative day, and walks with crutches on the seventh to tenth postoperative

day. The plaster cast is changed, with wire removal, during the fourth or fifth week. Weight-bearing in a plaster cast is started at eight weeks, and, three to four weeks later, the plaster cast is removed and physical therapy to the ankle is instituted. The patient is either fitted with a leg brace or high-top shoe, and weight-bearing with crutches is started.

OPERATIVE FINDINGS

The extent of the fracture, as noted when surgically exposed, was somewhat consistent with the roentgenographic interpretation of the injury; almost uniformly, however, the severity of the fracture was found to be greater than suspected. The appearance of the fracture was scrutinized in all roentgenograms prior to surgery, and an attempt was made to determine whether the fracture involved the cuboid articular surface. This involvement was shown by roentgenogram in twenty-five fractures and was verified in all of them at the time of operation. The involvement of the subtalar joint by the fracture was always found to be more extensive than was anticipated from the roentgenographic evaluation. Frequently, small, comminuted, detached, articular fragments were found which, in some instances, had been driven deep into the cancellous area. With fracture of the sustentaculum tali and associated longitudinal split in the posterior articular surface, the two articular surfaces formed a V, with fragments which had been driven down below the articular level. It was impossible to properly replace some of the smaller comminuted fragments, and it seems impossible to accomplish anatomical reduction of such a joint by closed or open procedure. The subluxation of the talus at the talonavicular joint was noted in some of the more severe injuries, but not with the frequency with which the fracture involved the cuboid articular surface.

ANALYSIS OF CASES

The data for the patients under study are presented in Table I and Table II. In order to reflect more precisely the result of primary triple arthrodesis, these patients have been divided into two groups: those without associated injury (Table I) and those with associated injury (Table II). The ages of the twenty-five patients treated ranged from twenty to sixty years, with an average of 41.4 years. Twenty-four patients were male; one was female. In Table I are included patients 5, 8, and 10 who had bilateral fracture of the calcaneus; Patient 5 had bilateral comminuted fractures; Patient 8 and Patient 10 had undisplaced fractures of the left calcaneus, which did not involve either the subtalar or calcaneocuboid joint and did not require operative treatment.

Of the twenty-six primary triple arthrodeses which were done, sixteen were on the right and ten were on the left. Twenty-one of these patients were laborers; fifteen of them had compensable injuries. Three other patients had injuries which involved liability claims.

The associated injuries, as listed in Table II, were those of: Patient 1, who had fracture of the second lumbar vertebra; Patient 2, who had comminuted fracture of the mid-shaft of the right humerus; Patient 3, who had fracture-dislocation of the left humeral head; Patient 4, who had multiple fractures involving the pelvis with acetabular displacement and a compound, comminuted fracture of the mid-shaft of the right femur; Patient 5, who had supracondylar fracture of the right femur and bimalleolar fracture of the right ankle; and Patient 6, who had an extensive comminuted fracture of the right tibia, involving the ankle joint, with displacement, necessitating ankle fusion.

RESULTS

The patients reviewed include all those on whom a primary triple arthrodesis was performed from 1948 through 1956. The duration of follow-up ranged from six months to more than nine years, with an average follow-up of 3.8 years.

Healing time of the triple arthrodesis, as judged roentgenographically by

restoration of trabeculae across the arthrodesed joints, averaged 3.2 months. Those patients without major associated injury returned to work on an average of six months after surgery, whereas those with associated injury required an average of eight months before returning to work. All patients returned to their former employment. The average time after surgery at which the twenty-five patients went back to work was 6.5 months. The average time at which the twelve patients with compensable injuries without associated injury returned to work was 5.3 months, whereas those of this group who did not sustain industrial injury returned to work in 7.3 months.

There was one complication, consisting of drainage, which began approximately six weeks after operation; culture and smear were negative. A staple at the calcaneocuboid joint was removed approximately four months after surgery, but minimum drainage persisted. Sequestrectomy of a bone fragment at the calcaneocuboid joint was performed approximately eighteen months after triple arthrodesis. This patient died two and one-half years after his injury from a rupture of an aneurysm in the circle of Willis; prior to his death, healing had occurred. Roentgenographically, this patient had a pseudarthrosis of the calcaneocuboid joint, resulting from sequestration of a fragment of bone at this joint. A pseudarthrosis at the talonavicular joint developed in another patient, but neither of these patients had symptoms referable to their pseudarthroses.

Twenty-one patients (84 per cent) were rated as having obtained excellent results. These were those who returned to their former occupations with no pain and no restriction of their activities. The loss of inversion and eversion which resulted from the primary triple arthrodesis was not considered by the patients to restrict any activity which they wished to perform. There was no detectable alteration in gait. Three patients (12 per cent) were rated as having obtained good results; they returned to their former occupations and had no serious interference with their activities although they all had a mild limp, mild discomfort, or some minor complaint. One patient was rated as having a fair result because of postoperative drainage; he, however, experienced no pain or restriction of physical activity and he walked with a normal gait. In some feet there was residual broadening of the heel, which has not, however, produced any functional impairment or symptoms.

In two patients with long-term follow-up, an exostosis developed on the dorsal aspect of the neck of the talus. This occurred in one of the feet of the patient who had had bilateral primary triple arthrodesis. Whether this condition results from the injury or from some other cause is not known. There was no significant impairment of ankle motion except in the one instance of an exostosis, as just described, in which there was 10 degrees of restriction of dorsiflexion.

An interesting observation was made in two patients who had had bilateral fractures of the calcaneus which were treated by a primary triple arthrodesis for the comminuted fracture on one side and by a short period of immobilization in a plaster cast for the undisplaced fracture on the other side. When re-evaluated, four and one-half and five years later, respectively, both patients stated that the foot treated by triple arthrodesis was more comfortable than the other foot.

CONCLUSION

From this study it has been found that the severe, comminuted, displaced calcaneal fracture is associated with involvement of the two peritalar joints consisting of fracture of the articular surface of the calcaneus at the calcaneocuboid joint and, in some instances, associated subluxation of the talar head at the talonavicular joint. The conventional projections are not adequate for the roentgenographic examination of the comminuted, displaced, fractured calcaneus, and two additional projections as described are necessary. Involvement of the two peritalar joints affords an explanation for some of the unsatisfactory results reported in the past. We believe that the injury to the talocalcaneal joint is irreparable and that fusion of this weight-bearing joint is necessary. The associated

injuries of the two peritalar joints similarly prevent the restoration of their normal function. It has been our experience that triple arthrodesis as the initial primary treatment of these fractures has given extremely gratifying results.

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DISCUSSION

Dr. John Hamilton Allan, Charlottesville, Virginia: Fractures of the calcaneus continue to remain the most disabling of all industrial injuries. One reason for this is that poor end results have been obtained by the various methods of closed reduction, and the discouraged surgeon, not caring to do arthrodesis or an open reduction, has concluded that simple immobilization is as good as any form of treatment.

There are several observations made in this paper which deserve emphasis:

1. It is imperative not to neglect this fracture, but to treat it early and definitively in order to prevent disability.

2. Comminuted fractures of the calcaneus cannot be treated successfully by any of the closed manipulative procedures.

3. Multiple roentgenograms projected as described are essential to reveal the major fracture lines and to determine whether the calcaneocuboid and talonavicular joints are involved. The extent of the fracture damage is always much greater when visualized directly than it is in the roentgenogram.

4. The calcaneocuboid joint is involved in so many of these fractures that, as a general principle, the results with arthrodesis are somewhat better than they are with subtalar fusion.

Finally, in the technique of their operation the authors state that reduction and apposition of the fractured surfaces are accomplished under direct vision. This is of significance because it is an accepted orthopaedic principle that joints should be fused in their normal anatomical and functional position. When applied to the comminuted displaced calcaneus, this means that the tuberosity must be pulled down, the posterior articular facet elevated to its normal position, and the lateral spread corrected at the time of the fusion so that a good functional position of the foot is retained.

In one respect our experience with these fractures does not agree completely with that of the authors. This paper deals with comminuted fractures involving the subastragalar joint, and the classification includes those with centrolateral depression of the joint. The authors stated that these fractures all exhibit extension forward into the cuboid articular surface. It is agreed that when the fracture line disrupts the calcaneocuboid joint, arthrodesis is indicated. However, there are many fractures of the calcaneus which present primary or secondary depression of the posterior articular facet and which do not extend forward into the calcaneocuboid joint. These are the ones which respond beautifully to an open reduction, elevation of the posterior articular facet, and insertion of a bone graft into the compression cavity as described by Palmer. Some lateral motion through the foot should be preserved if possible.

I must conclude, therefore, that most comminuted fractures of the calcaneus will require the treatment advocated in this paper. However, the treatment must be designed to fit the pattern of the fracture, and, in many carefully selected cases, open reduction and retention of the reduction by the Palmer technique will give an excellent result and preserve the lateral motion through the foot.

A Questionnaire Survey of Juvenile to Young-Adult Amputees Who Have Had Prostheses Supplied Them through the University of Illinois Division of Services for Crippled Children

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The purpose of this survey was to obtain information which would be helpful in evaluating various services to juvenile and young-adult amputees. The term juvenile amputee is used by us more broadly than in the usually accepted definition, as the Division gives service to amputees from the time of referral until they are twenty-one years of age. The age groups were evaluated as preschool (under five years old), young school-age, and preadolescent (six to twelve years old), adolescent (thirteen to seventeen years old), and young adult (eighteen years old and over). The amputees under discussion were under the medical supervision of clinics throughout the State. The interest of the orthopaedists and their training in amputee rehabilitation varied widely.

In general, the personnel within the various disciplines (orthopaedists, physiatrists, pediatricians, therapists, psychologists, nurses, medical social workers, prosthetists) with whom we got in touch agreed that the most effective approach to the rehabilitation of amputees is an integrated program involving psychological preparation of the juvenile amputee and his parents; surgery as needed, with aftercare of the stump preparatory to the prosthetic fitting; selection of and fitting of the prosthesis most suited to the amputee's needs; training in the use of the prosthesis; and follow-up evaluation of the patient's ability to adjust to daily living function and to undergo eventual vocational rehabilitation. The questions in this study were therefore designed to obtain information regarding these factors.

The questionnaire (see appendix) was sent out in April 1955 to parents of juvenile amputees who had been fitted with prostheses by the University of Illinois Division of Services for Crippled Children from July 13, 1945, to March 9, 1955. The latest recipient of a prosthesis had had it for two months and two days at the time of the questionnaire. A total of 363 questionnaires were sent: 197 were returned, but 15 were not used in this report because of meager or incomplete replies. The number not returned was 121; 45 were returned undelivered. In evaluating the results of these questionnaires an attempt was made to determine whether or not we had improved the juvenile amputees' adjustment to life, guided them toward as full independence as possible, and helped them as individuals to find their places in our whole society.

STATISTICAL STUDY

This study included 182 amputees with 198 amputations of whom 124 (68.1 per cent) were male and 58 (31.9 per cent) were female. The greater number of male amputees is due to a higher incidence of traumatic and congenital amputations as well as to a higher incidence of amputations caused by disease (infections and arterial insufficiency) among males in this series. Of the amputations, 94 (51.65 per cent) were traumatic; 71 (39.01 per cent) were congenital; 10 (5.5

per cent) were due to malignant growths; and 7 (3.85 per cent) were due to disease. In the group of 124 male amputees, 73 amputations (59 per cent) were traumatic; 41 (33 per cent) were congenital; 5 (4 per cent) were due to disease; and 5 (4 per cent) were due to malignant neoplasms. Of the 58 female amputees, 30 amputations (52 per cent) were congenital; 21 (36 per cent) were traumatic; 5 (9 per cent) were due to malignant growths; and 2 (3 per cent) were due to disease.

Among the patients with amputations caused by trauma, there were 73 (77.7 per cent) male patients; the amputations were: 10 below the elbow, 19 above the elbow, 29 below the knee, 11 above the knee, and 4 were multiple. There were 21 (22.3 per cent) female patients; the amputations were: 1 below the elbow, 3 above the elbow, 9 below the knee, and 8 above the knee.

Among the patients with congenital amputations there were 41 (57.7 per cent) male patients; the amputations were: 10 below the elbow, 3 above the elbow, 16 below the knee, 5 above the knee, and 7 were multiple. There were 30 (42.3 per

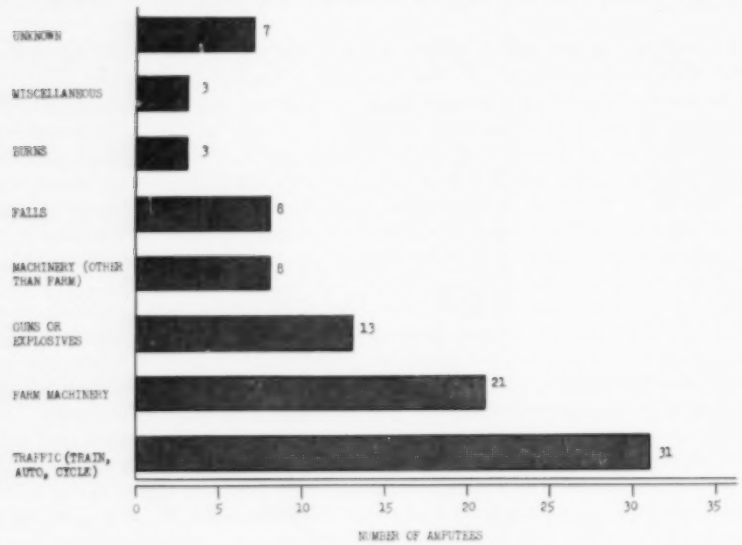

CHART I

Causes of 94 traumatic amputations.

cent) female patients; the amputations were: 12 below the elbow, 1 above the elbow, 8 below the knee, 7 above the knee, and 2 were multiple.

In the group of patients with amputations resulting from disease, there were 5 (71.4 per cent) male patients; the amputations were: 4 below the knee and 1 above the knee. There were 2 (28.6 per cent) female patients; the amputations were: 1 each above and below the knee.

In the group of patients with amputations required because of malignant neoplasms, there were 5 (50 per cent) male patients; the amputations were: 1 below the knee and 4 above the knee. There were also 5 (50 per cent) female patients; the amputations were: 1 below the elbow, 1 below the knee, and 3 above the knee.

When the numbers of patients having amputations due to both neoplasms and disease were combined, there were 10 (58.8 per cent) male and 7 (41.2 per cent) female patients.

The types of amputations in this series were classified rather simply as being either above or below the elbow in the upper extremity or above or below the knee in the lower extremity. More technical studies indicate the size of the stump

in inches or designate the stumps as short, medium, or long, or above or below a joint. Further classification, in regard to the upper extremity, may specify shoulder, elbow, or wrist disarticulation, and partial hands; in regard to the lower extremity it may specify hemipelvectomy, hip, knee, or ankle disarticulation, and partial feet. We did not believe that such distinctions could be made in this type of study, and the questionnaire was incomplete in this respect.

The greatest number of amputations—94—were due to trauma; the causes are listed in Chart I. It is evident that more emphasis is needed on educational measures to prevent accidents caused by automobiles, trains, motorcycles, farming, and firearms. Immediate care of even supposedly minor injuries is also indicated. For example, two amputations in this series were necessary after one youngster crushed his finger in a door and tetanus and gas gangrene developed and after another youngster cut his foot on a can in a fall and a chronic osteomyelitis developed.

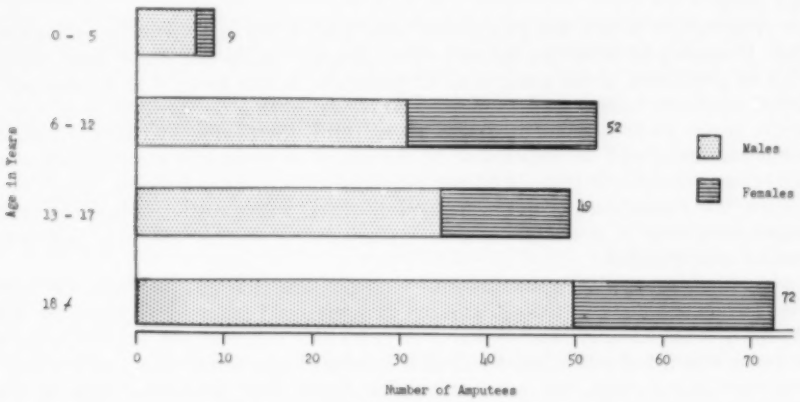

CHART II
Age of the amputee when the questionnaire was sent.

These accidents occurred at ages which ranged from 1½ to 19 years. The group 6 to 12 years of age was the most vulnerable to accidents leading to amputations, since 40 (42.55 per cent of all accidents) occurred in this age group. The preschool group was next with 24 (25.53 per cent). The teen-age group (13 to 17 years) was a close third with 22 (23.41 per cent). This indicates the need for more intensive programs in safety education and accident prevention, closer supervision by parents or other responsible adults, and the removal of so-called attractive nuisances.

In the group of 71 congenital amputees were included 39 youngsters born with an amputated extremity; 27 who had an anomalous extremity leading to a conversion amputation of whom 2 also had a true amputation; and 5 with a congenital defect of the vascular or lymph system which led to surgical amputation. Of the congenital amputations, those below the knee occurred most frequently, followed in order by those below the elbow, above the knee, multiple, and, lastly, above the elbow. Here it seems that in congenital amputations, the right side is more likely to be involved, since, in 62 patients with unilateral congenital amputations, 40 (64.5 per cent) had right-sided involvement as against 22 (35.4 per cent) with left-sided involvement.

The 10 amputations for malignant growths were because of: liposarcoma, carcinoma, sarcoma, fibrosarcoma, neurofibroma, and Ewing's sarcoma. The 7 amputations due to disease were because of: osteomyelitis, Pott's disease, and emboli.

The greatest number of referrals, which was 112, to this Division were from doctors or ancillary medical services; 53 were from the family physician; 34 were

from the public-health nurse; 1 was from the surgeon; 24 were from the hospital staff; 30 were from the limb-manufacturing companies; and 32 were from some other source (school staff, social or welfare agencies, friends, and the like). In 8 instances this question was not answered.

AGE DISTRIBUTION

At the time of this study the age distribution was 18 months to 27 years (Chart II). As stated earlier, this questionnaire was sent to all the juvenile amputees who were fitted with prostheses by the University of Illinois Division of Services for Crippled Children between July 13, 1945, and March 9, 1955. Only about one-fourth of the amputees in this study were under the care of the University of Illinois Amputee Clinic, which was established in 1952. About one-third of the amputees were first fitted with prostheses at 12 or more years of age, which accounts for the high upper-age limit at the time the questionnaire was sent.

The age at which the youngsters were first fitted with prostheses ranged from 9 months to 20 years. Seventy-four patients (40.66 per cent) were fitted with 80 prostheses in the group 6 to 12 years old; in the group 0 to 5 years old, which was next, there were 56 patients (30.77 per cent) fitted with 58 prostheses; in the group 13 to 17 years old, which was third, there were 41 patients (22.53 per cent) fitted with 45 prostheses; in the group 18 years and older, which was last, there were 11 patients (6.04 per cent) fitted with 11 prostheses. In all age groups, the majority of amputees who were fitted with prostheses had acquired amputations except in the group 0 to 5 years old, where the majority had congenital amputations.

In the group with below-the-knee amputations, the greatest number were fitted with prostheses in the age group 0 to 5 years old followed, in order, by the groups 6 to 12, 13 to 17, and 18 and over years old. The youngest below-the-knee amputee was fitted with a prosthesis at 9 months of age. In the group with above-the-knee amputations, the greatest number fitted with prostheses were in the group 6 to 12 years old followed, in order, by the groups 0 to 5, 13 to 17, and 18 and over years old. The youngest above-the-knee amputee was fitted with a prosthesis at 13 months of age. Some lower-extremity amputees were fitted with pylons when they were less than 9 months old.

The 60 patients with unilateral upper-extremity amputations were first fitted with prostheses when they were from 3 to 20 years of age. In the group with amputations above the elbow and in the group with amputations below the elbow, the majority were first fitted with prostheses in the age group 6 to 12 years old followed, in order, by the age groups 13 to 17, 0 to 5, and 18 years and over. The youngest below-the-elbow amputee was fitted with a prosthesis at 3 years of age; the youngest above-the-elbow amputee, at 5 years of age.

SURGICAL PROCEDURES

With acquired amputations, reconstructive or reparative surgery may be required, either initially or for revision of the stump. It is important for the surgeon to keep in mind the fitting of the prosthesis at the time of surgery, whether it be the initial surgery or revision of the stump[5,6]. Surgical problems of juvenile amputees differ from those of adults[7]. In this study no definite conclusions could be drawn concerning the results of the surgery. The question concerning this was not only poorly worded but also failed to cover the various aspects of this subject. Some of the patients or their families or both thought that this question related only to surgery being necessary after the child was referred to this Division for a prosthesis. Several interesting factors were noted: the younger the child at the time of the initial amputation, the greater was the likelihood of one or more revisions being necessary; and the below-the-knee amputees, followed by the above-the-elbow amputees, had more revisions than

those in other groups. Some youngsters had as many as three revisions. We did not find a single below-the-elbow amputee who had a revision because of overgrowth of one or both of the forearm bones at the distal end of the stump.

The surgical procedures on most of the lower-extremity congenital anomalies were performed to convert a deformed extremity to an amputation. Most of these amputees had had other treatment previously, including casts, braces, built-up or extension shoes, and other surgical procedures such as subtrochanteric osteotomy, bone grafts, growth arrest of the normal leg, and surgical correction of a chronic dislocating patella. Three below-the-knee amputees with short femora were treated by arthrodesis of the knee and were then fitted with above-the-knee prostheses. There were fewer stump revisions in this group of amputees than in groups whose amputations were owing to other causes. Rarely, except in congenital lymph hemangiomata and arteriovenous fistulae, is a congenitally deformed upper extremity amputated. Surgery—such as the removal of rudimentary nubbins, the correction of other deformities (such as webbed fingers), and derotation osteotomies—was done in the upper-extremity amputees. Some parents refused to allow the recommended amputation because they lacked understanding of the child's deformity. Other parents preferred to wait until the child could make the decision. One child in this study was 19 years old before he requested surgical treatment.

Systematic stump hygiene is important [8,9]. The doctor, nurse, and therapist should give definite instructions. The following is suggested: the stump should be cleansed daily with a mild soap (in specific instances a germicidal soap may be recommended), dried thoroughly by patting rather than rubbing, and aired at intervals, especially in cases of excessive perspiration. Stump socks, if they are worn, should be clean (it is important to give instructions as to the care and laundering to keep them soft and to reduce shrinkage). Cleaning the sockets of the prostheses is especially important if stump socks are not worn. Close watch for redness or break in skin or any other signs of irritation is essential so that prompt treatment may be given as necessary.

According to the replies to the questionnaire, 75 amputees or parents had received some instructions, whereas 26 had had none, and 4 misunderstood the question and gave answers concerning the care of their prostheses. In 77 instances the question was unanswered. Several amputees or parents indicated that their only instructions were given to them by the prosthetists. It is fortunate that skin problems are not common in juvenile amputees. Many of the amputees in this series had amputations prior to their referral to this Division. This does not excuse the failure to give these patients instructions in stump care or to at least review them. It may be that instructions were given but not sufficiently stressed. Perhaps they need to be repeated several times. The answers to this question emphasize the need for the responsible personnel to review the instruction in stump care more completely with the amputees or their parents, or both.

ATTITUDES OF PARENTS

The education of the family is of the greatest importance since the parents supervise the child's total care, and the child interprets his defect according to what it means to his parents. Once the parents have insight into the total program of habilitation, or rehabilitation, as the case may be—just being reconciled to the defect is not enough—a plan can be worked out for the child [1,2,3]. Of the 182 replies, 165 persons said that they understood the findings and recommendations of the clinician and the other members of the clinical staff as to plans for their children; 3 said that they needed more interpretation; and 14 did not reply. From these replies, it would seem that most of the families have had no problems from this standpoint, but that this obviously was not so was indicated in replies to other questions. In 29 instances the parents said that they felt the

need for more time at the clinic (some of them had previously said that they understood what had been said to them). The parents of above-the-elbow and above-the-knee amputees felt this need more than parents of the other amputees.

Most of the parents replied to the third part of this questionnaire concerning how the staff might be more helpful. Some parents said that the clinicians expected too much from the children. Other parents stated that the clinicians did not expect enough and could get the children to do more. Many wanted to know how to help the child overcome his self-consciousness.

All but 1 parent indicated that their children had accepted the idea of being fitted with a prosthesis. The replies to the two subsections of this question revealed, however, that the children (or perhaps the parents themselves) had not accepted the idea of a prosthesis. For example, although only 1 parent said that his child did not accept the idea of a prosthesis, 52 parents replied to part (a) of question 5, and of these, 33 said that they had discussed this problem with the clinic staff. Many parents explained in part (b) of this same question how they helped their children's attitudes toward prostheses. Some said that they compared prostheses to false teeth. Others said that their youngsters were too young to know and therefore accepted the prosthesis. Some complained that the prostheses were recommended too early (in the cases of upper-extremity amputees only). Many urged amputees to be fitted with prostheses as early as possible. Some asked for pointers on how to explain the usefulness of the prostheses to the child.

Several parents gave information regarding the assistance that they gave their youngsters in dealing with the curiosity of, and teasing by, others. Some parents suggested that other amputees visit their youngsters to see how much could be accomplished. Some parents (of congenital amputees only) suggested that parents' clubs be formed. It would seem from this that these parents feel a greater need for this type of group therapy. Classes for parents of congenital amputees have been found helpful at the Kessler Institute for Rehabilitation [4].

The parents of patients with acquired amputations accepted the defect and the use of a prosthesis more readily than the parents of the congenital amputees. Several parents of children with upper-extremity amputations (both congenital and acquired) were more interested in hiding the deformity than in function. Some believed that the prosthesis made the deformity more obvious. Several parents of upper-extremity amputees stated that they had not cooperated in helping their children use their prostheses, but would do so in the future. Many parents of children with lower-extremity amputations (congenital and acquired) stated that very few outsiders knew of their child's amputation. Some parents were very hostile toward society. A few suggested issuance of inexpensive, informative pamphlets.

There seemed to be a definite correlation between the parental acceptance and the child's adjustment to not only his amputation and prosthesis, but also to his general adjustment in his daily activities. Some parents encouraged a variety of activities; others suggested how parents might introduce new activities for their youngsters; and still others asked to have their youngsters excused from certain activities in school or other group activities.

PROSTHETIC FITTING AND ADJUSTMENT

A prosthesis should not be prescribed unless the child is physically ready and the parents are mentally, emotionally, and socially ready for it. The child's readiness is strongly dependent on the readiness of his parents. Sometimes it is necessary to delay prescribing a prosthesis if the amputation is done for a malignant growth. The child should be checked periodically, both clinically and by roentgenograms, for the presence of metastases. Six months is the usual period allowed to lapse before prosthetic prescription. The periodic check-ups for metastases should continue after the prosthesis is provided.

In this study, the interval between the surgical amputation and the prosthetic fitting varied from 1 month to 11 years after operation, excluding the cases with malignant growths. Most were fitted within a year after operation. Some of the upper-extremity amputees were not fitted for several years, particularly those patients seen prior to 1951, principally because of the types of prostheses available at the time. After 1951, the latest developments in upper-extremity prostheses were made available to us.

A total of 182 amputees were fitted with 194 prostheses. In 65 amputees with 73 amputations (26 above the elbow, 34 below the elbow, and 5 multiple) the patients were fitted with upper-extremity prostheses and the following terminal devices: hooks only, 34; hands and hook, 27; and hand only, 4. In many instances, the hooks and hands were provided at the same time. Prior to 1951, only cosmetic or dress hands were provided. After 1951, APRL hands became available and were supplied to 9 amputees in this study. The current practice at the University of Illinois Hospitals Amputee Clinic is to provide an APRL hand (if the child's natural hand is near the size of the currently available APRL hand) only after he has learned to use his hook well and is wearing his prosthesis regularly. Cosmetic or dress hands are seldom recommended, and therefore an amputee usually is in his teens before he obtains a hand. Some parents bought dress hands for their children.

Of the 65 amputees with 73 amputations, 32, of whom there were 29 with unilateral amputations (14 above the elbow and 15 below the elbow) and 3 with multiple amputations, wore their prostheses all day; 13 amputees (5 with above-the-elbow and 8 with below-the-elbow amputations) wore their prostheses for five to eight hours; 8 amputees, of whom there were 7 with unilateral (1 above the elbow and 6 below the elbow) and 1 with multiple amputations, wore their prostheses for three to four hours; and 12 amputees, of whom there were 11 with unilateral (6 above the elbow and 5 below the elbow) and 1 with multiple amputations, wore their prostheses for less than three hours.

Of the 65 amputees with 73 amputations who were fitted with upper-extremity prostheses, 26 (40 per cent) had complaints: pain in the stump or skin irritation in 12; poor fit of the socket in 1; shortness of the stump, making the limb hard to use, in 1; and dissatisfaction with the appearance or no functional benefit in 12. For these youngsters, the functional value of the prostheses in many instances was not sufficient to overcome the discomfort. Regardless of whether the discomfort was organic or emotional, the youngsters did not wear their prostheses regularly.

The extent of the use of upper-extremity prostheses was graded as good, fair, and poor. Good use, which implies that the amputee uses the prosthesis consistently in a diversity of activities as a hand strongly supportive to the natural hand, was reported in 36 instances. Fair use, which implies moderate but active and consistent use within certain areas of activity, was reported in 8 instances. Poor use, which implies that the prosthesis is seldom worn or worn merely as an added appendage, the amputee performing primarily one-handedly, was reported in 21 instances.

A close correlation was found between the length of time that the prosthesis was worn daily and the extent of use. Of the 32 amputees who wore their prostheses all day, 30 had good use and 2 had poor use. Of the 13 amputees who wore their devices for five to eight hours, 5 had good use; 6 had fair use; and 2 had poor use. Of the 8 amputees who wore their devices for three to four hours, 1 had good use (he had a claw hand and wore a hand terminal device for cosmetic purposes only, as he had his own "hook"); 2 had fair use; and 5 had poor use. All 12 amputees who wore their prostheses for less than three hours had poor use.

To the question, "Could the amputee do things faster with the hook terminal device?" there were 43 replies from 65 amputees: 12 replied "yes"; 14 replied "no"; and 17 replied "sometimes". Thus, 29 (67.4 per cent) of these 43 amputees

could do things faster either sometimes or regularly when using their hook terminal devices. It is interesting to note here that not one amputee with poor use of the prosthesis answered "yes", and only 3 with poor use answered "sometimes". All except one of the amputees with good use of their prostheses answered "yes" or "sometimes".

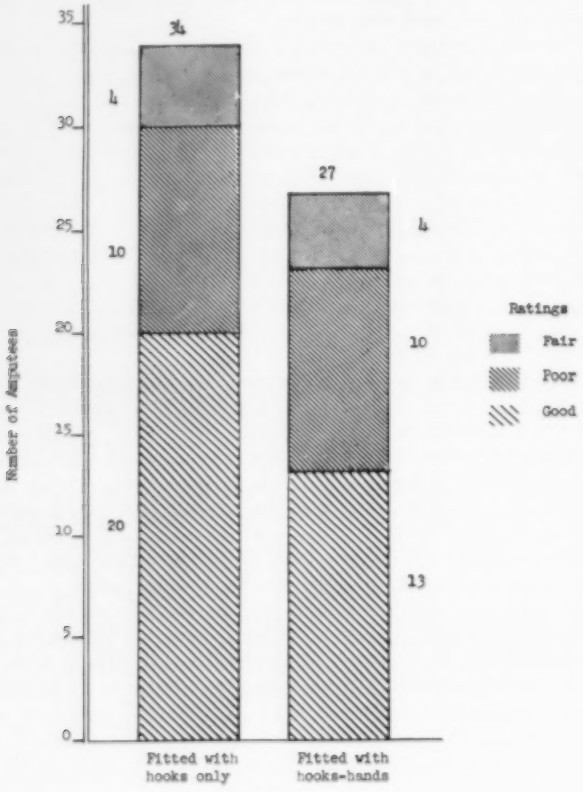

CHART III

Comparison of the ratings of the use of prostheses by 34 upper-extremity amputees fitted with hooks only and 27 fitted with hooks and hands.

The ratings of the amputees as to the usage of the prosthesis were compared (Chart III). In 27 amputees who were fitted with hook and hand terminal devices there were 13 (48.1 per cent) with good usage; 4 (14.8 per cent) with fair usage; and 10 (37.037 per cent) with poor usage. In 34 amputees who were fitted with hooks only, there were 20 (58.8 per cent) with good usage; 4 (11.764 per cent) had fair usage; and 10 (29.4 per cent) had poor usage. These figures indicate that the providing of hands, as well as of hooks, did not improve the children's adjustment to their prostheses; the more basic psychological needs were not met.

The sex of the child with upper-extremity amputations did not seem to be a significant factor in his adjustment. The cause of the amputation, the dominance of the hand, and the interval between amputation and fitting with the prosthesis seemed to have no specific effect on the adjustment of the child with amputations above the elbow.

Training seemed to be important among children with amputations above the elbow. Of the 11 who had "use" training (by trained professional personnel),

7 wore their prostheses all day; 1 wore his for five to eight hours; 1 wore his for three to four hours; and 2 wore theirs seldom or not at all. The 2 children who had "controls" training (by the manufacturer), both wore their prostheses all day. Of the 13 children who had no training, 5 wore their prostheses all day; 4 wore theirs for five to eight hours; and 4 wore theirs seldom.

We found that the child with a congenital amputation below the elbow was not so good about wearing his prosthesis as the child with a traumatic amputation below the elbow.

Of the 22 children with congenital amputations, 7 (31.8 per cent) wore their prostheses all day; 7 (31.8 per cent) wore theirs for five to eight hours; 5 (22.7 per cent) wore theirs for three to four hours; and 3 (13.6 per cent) wore theirs for less than three hours. Of the 11 children with traumatic amputations, 8 (72.7 per cent) wore their prostheses all day; 1 (9 per cent) wore his for five to eight hours; 1 wore his for three to four hours; 1 wore his less than three hours.

Only 9 of the 22 children with congenital amputations below the elbow made good use of their prostheses, whereas 10 of the 11 children with traumatic amputations made good use of theirs. We wonder if this situation could be due to the greater time interval between the congenital amputation and the fitting of the prosthesis. Eight children (the majority) with traumatic amputations were fitted with prostheses 1 year or less after surgery, 2 children were fitted later but less than 2 years after surgery, and 1 child was fitted 11 years after surgery (he had had a partial hand amputation). The youngest of the children with congenital amputations below the elbow was fitted with a prosthesis at 3 years of age; the majority of the children in this group were fitted when they were between 6 and 12 years old. Some parents of the children with congenital amputations below the elbow said that the children did not wear their prostheses because they had learned to do everything with one hand; other parents said that the prostheses were in the way.

The suggestion was made that if the amputees had been fitted prior to 1951 they would have received so little training that they would be reluctant to use their prostheses. It was found, however, that 15 of the 22 children with congenital amputations below the elbow had been fitted after 1951, and from a review of the records it was obvious that the preparation of the parents or amputees, or both, had been inadequate.

The statistics also indicated that the earlier a child with a congenital amputation below the elbow is fitted with a prosthesis, the more likely is he to be a good prosthesis wearer. Children first fitted up to 5 years of age were the best wearers, those from 6 to 12 years old were the next best, and those 13 to 17 years old were the poorest wearers.

The side involved seemed to have some effect on the adjustment of the child with an amputation below the elbow. In this small series it appeared that a child with a congenital amputation below the elbow was a better prosthesis wearer if the left hand, which should have been the supportive hand (as judged from the statistics on handedness in the general population), rather than the right, or dominant, hand was involved. In contrast to this finding, the child with a traumatic amputation below the elbow seemed to be a better prosthesis wearer when the dominant hand was involved.

In this study it was found that children with traumatic amputations below the elbow were good prosthesis wearers whether or not they had had training, whereas children with congenital amputations below the elbow were not good wearers even though more of them had training. The dexterity of those who had received little or no training could not be evaluated.

All but 1 of 119 children (109 with unilateral and 10 with multiple amputations) who were fitted with lower-extremity prostheses wore their prostheses all day. The one exception was less than 1 year old and wore the prosthesis during all the time he was awake.

Of the 119 children with lower-extremity prostheses, 10 (8.4 per cent) complained of either pain in the stump or skin irritation, and 1 complained of poor fit of the socket. Nevertheless, they still wore their prostheses all day.

The extent of use of prostheses by the 109 children with unilateral lower-extremity amputations was graded according to the child's participation in activities.

Above-average use of the prosthesis implies that the child either participates in a wide variety of activities or does not object to the prosthesis or stump being exposed, or both.

Average use of the prosthesis implies that the child participated in a fairly wide variety of activities but preferred not to engage in any in which the prosthesis or stump would be exposed.

Below-average use of the prosthesis implies that the child participated in few activities and would not engage in any in which the prosthesis or stump would be exposed. Either the child or his parents asked for his excusal from the activities.

The extent of use of lower-extremity prostheses is shown in Chart IV. It was noted that the child with an amputation above the knee is less likely to participate in activities in which his stump or prosthesis is exposed.

The sex of the child, etiology, the side involved, the training, the age when he was fitted with the prosthesis, and the interval between the amputation and the fitting seemed to have no effect on the way in which the child with a lower-extremity amputation adjusted to the prosthesis. Gait, balance, posture, and the like, however, could not be evaluated.

TRAINING

Training by a qualified therapist in the use of the prosthesis is essential in the rehabilitation of the amputee[5,6,10,11,12]. The training must be adequate to be effective. The amount of training that is adequate varies according to the type of amputation, the prosthetic fitting, the age of the patient, the attitude of the amputee and of the parents, and the amputee's general muscle tone and coordination. The objective of therapeutic exercises and training in the use of a prosthesis is to get maximum effective function of the prosthesis under normal daily living conditions. When a prosthesis is replaced it is considered good practice to review functions, activities, and care with the patient, but usually additional training is not necessary unless a new type of component has been added. Checkout of a new prosthesis to determine whether or not it meets with certain standards is a part of this training. The occupational therapist or the physical therapist, or both, may be involved in the training program.

Gait training, posture, and balance are the usual goals for a patient with an amputation of the lower extremity. The training of the juvenile patient with an amputation of the upper extremity is more difficult. The guides for activities of daily living for adult-amputee training are helpful. Many therapists use the findings of research on the development of children as guides in the training of the juvenile amputee. In general, training starts with play and self-care, followed by various activities leading up to as full independence as possible and eventual educational or vocational rehabilitation, or both. If the child has a hand terminal device as well as a hook, additional training may be needed.

Some of our teen-age patients with traumatic below-the-elbow amputations have become adept in the use of their prostheses in 3 days of training on an in-patient basis. Patients with other types of amputations and younger amputees take an average of about 10 days of training on an in-patient basis. The youngsters who have multiple needs or have complicated fitting problems require longer periods of hospitalization. During this time, the nurses help to carry on the training suggested by the therapists in the daily care and play activities of the patient. Out-patient therapy extends over a longer period of time. Some

amputees are able to come in daily, whereas others come three times a week. Gradually, these visits become less frequent. Here again, the type and duration of therapy depend on the individual needs of the amputees. The amputees are expected to master certain functions before training is discontinued.

In the replies to the question concerning training in the use of the prosthesis there was some confusion, in a few instances, with vocational training. The following data, however, were obtained: of a total of 182 amputees fitted with

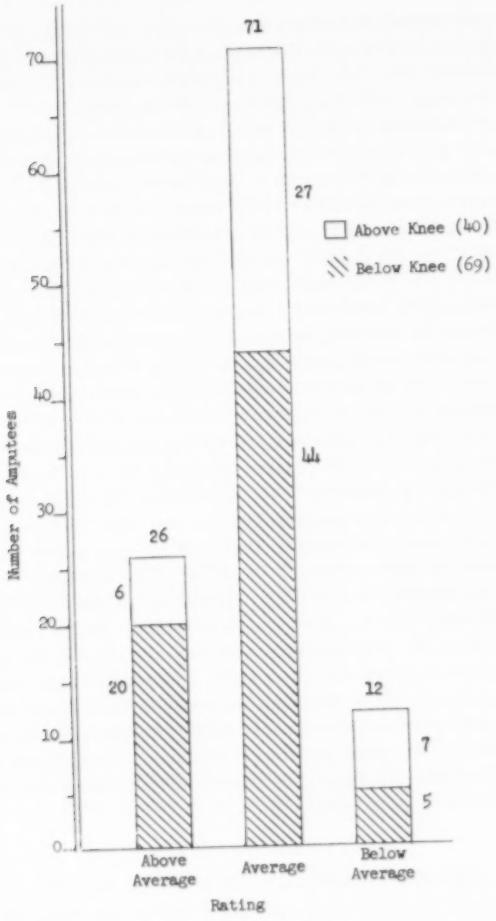

CHART IV

Extent of use of lower-extremity prostheses.

prostheses, 90 said that they had had training; 83 said that they had had none; and 9 did not reply. Of the 90 who said that they had had training, 61 had had "use" training (training by professional therapists) in hospitals, special schools, or treatment centers; 19 had had "controls" training (training by limb manufacturers); and 10 indicated that they had had training by only answering "yes". Of the 42 parents (or patients) who thought that more training would have been helpful, 35 thought that more training was needed to make the patient more independent and able to take better care of the prosthesis. Some respondents said that more encouragement was needed, and others felt the need of a review.

The parents of several children with upper-extremity amputations who had received no training stated that if the children had had training they would have made better use of the prostheses. Parents of children with lower-extremity amputations also stated that if the children had received training they would have walked better or would have better posture, or both. Thus, the comments of many parents indicated that they realized the importance of training. Several parents, who apparently believed that the therapists who had trained the children were inadequate, stated that all therapists should have training with amputees.

Generally, additional training (called "keep-up training" by several parents) as such is not necessary after the child has received adequate training. Usually, an amputee who has been adequately trained in the basic functions quickly learns to apply this training to other activities.

Most of the amputees who had poor use of their prosthesis (poor wearers) and their parents need considerable help in developing better personal relationships. For instance, the child needs to feel loved and wanted, and the parents should express such emotion toward the child and help him to develop greater independence. Both the parents and the amputees need more interpretation of their own feelings about the defects, the injuries, and the prostheses.

The duration, quality, and adequacy of the training, or whether it was on an in-patient or out-patient basis could not be critically evaluated. However, prior to about 1951, plans for training were not routine, and there were few therapists trained in working with amputees. Often, training was not recommended as some of the clinicians seemed to feel that the instructions available from the manufacturer were adequate.

Now, plans for training are arranged as needed. Wherever resources permit, arrangements are made for out-patient training. It has been our feeling that hospitalization should be reserved for the seriously ill child or one needing surgery. In-patient training is arranged if there are such factors as large families, illness in the family, long distances to travel, if the prosthetic problem is a complicated one, and if intensive training is needed. The amount of time varies with the patient and his specific needs. The parents are included in this training program and are instructed in the care of the prosthesis, in training in its use, and in ways to encourage the youngsters to use their prostheses in additional activities. The very young amputees (less than 12 months) are usually not given formal training as such; their training amounts to functional play therapy and help in the development of balance and the ability to get about at will, as the needs may indicate. Instruction of the parents is especially emphasized during visits for occupational or physical therapy. In-patient therapy may be arranged for the very young amputee if necessary.

FOLLOW-UP

Fitting the child with a prosthesis and teaching him to use it expertly does not necessarily mean that he will make good use of his prosthesis. He needs to be seen periodically not only to check his use of it in every-day activities but to encourage him in additional activities [10,12]. The length of the time interval between clinic visits varies—it may be as often as once a month during the period of rapid growth, after the first fitting with the prosthesis, or in the event that a difficult fitting problem is encountered. Parents and patients are advised to feel free to get in touch with the clinic or field staff earlier, if necessary. On these clinic visits: the family may be given further instructions in the care of the stump if skin irritations have arisen, a stump revision may be found necessary, repairs or adjustments of the prosthesis may be made, a new prosthesis may be ordered, bad habits in the use of the prosthesis may be prevented or corrected, and the family may be given further suggestions regarding the use of the prosthesis.

Of the 136 persons who replied to the question about clinic recheck exami-

nation, 68 (49.9 per cent) stated that they return to clinic every 6 months; 29 (21.3 per cent) return to clinic every 3 months; 26 (19.1 per cent) return yearly; and 13 (9.5 per cent) return at various intervals. It was also found that the non-wearers and the poor users kept clinic appointments in about the same fashion as the good wearers.

Repairs and adjustments (to which there were 114 replies) were needed at intervals ranging from 3 months to more than 1 year. The cost of upkeep is therefore an important consideration. The repairs most frequently needed were: replacements of straps, leather and rubber parts, and screws and bolts; new joints; new washers; new feet (for the below-the-knee more often than for the above-the-knee amputee); new pelvic belts for above-the-knee amputees; repair of fingers; and new cables and new harnesses. The below-the-knee amputees needed the most repairs; next came the below-the-elbow amputees, then above-the-knee amputees, and, finally, above-the-elbow amputees. The families contribute toward the cost of repairs according to their ability to pay. The need for repairs (unless due to neglect or abuse) is an indication that the amputees are using their prostheses. Because the cables break frequently two cables, or cable units, are now supplied to the upper-extremity amputees. When one breaks, the spare is applied, and parents are advised to replace the broken one as soon as possible so that a spare will always be available.

There were 98 replies to the question as to how long the first limb had remained satisfactory (59 amputees in this study had been fitted with their initial prosthesis only). There were 30 (30.6 per cent) who had used their limbs for 3 years; 30 (30.6 per cent) for 2 years; and 26 (26.5 per cent) for 1 year, and 12 (12.6 per cent) whose limbs lasted for various periods. The problem of a limb that is outgrown before it is outworn is ever present, and every effort is made to cope with it. On an over-all basis, however, the cost per amputee is one of the lowest expenditures, and the results, in most instances, more than justify the outlay of funds.

The questions did not consider other aspects of follow-up care. Clinic follow-up is supplemented by home visits, school visits, and conferences with other persons or agencies concerned with the patient's adjustment. The community nurse is the key person in integrating the total care of the juvenile amputee. State and local agencies for education, public health, and social welfare, both voluntary and government, the amputee's family physician, pastor, school counselors or other school personnel, the local public-health nurse, the caseworker, local therapists, psychologist, or some fraternal group—in fact, almost anyone who is needed to help in the child's and the family's adjustment—may be involved in the rehabilitation of amputees. Acceptance at home alone will not suffice. The child must have happy group experiences.

SOCIAL ACCEPTANCE

An important factor in the juvenile amputee's adjustment is his acceptance by various individuals and groups outside the home, such as neighbors and church, school, and recreational groups. Problems concerning children with lower-extremity amputations are rare. Considerable prejudice against children with upper-extremity amputations exists, however, and this seems to increase when the child is fitted with a hook prosthesis. A recent survey indicates the need for further study of societal influences on amputees [13]. A close correlation has been found between the degree of acceptance of the child with upper-extremity amputations in these outside relationships and the development of a satisfactory attitude toward the handicap and the prosthesis by the child and the family. Both the parents and the child may need help in their approach to others so that it enhances rather than aggravates the situation when the youngster meets other people.

In many instances, of course, social prejudice is a product of ignorance and

superstition. Education of the public is the answer here as it is with other problems of prejudice. This educational process needs to be continuous to be effective.

There is a trend to send these youngsters, unless severely handicapped, to regular school, although this trend has not yet been generally accepted. Schools frequently accept the youngsters, but the parents, however, want the child to attend a special school. Free transportation to and from special schools seems to influence some parents.

Of the 133 amputees who answered the question concerning whether or not they wore their prostheses to school, all but 14 replied in the affirmative. Of these 14, 1 had multiple amputations, 5 had above-the-elbow amputations, and 8 had below-the-elbow amputations. It is interesting that in this study not one parent said the school would not permit the child to wear the prosthesis.

Of the 121 who replied to the question concerning activities permitted in school, 100 said that they were permitted to wear their prostheses in all activities. The activities prohibited by some schools were swimming, gymnastics, baseball, and football. (Swinging was not permitted for some children with upper-extremity amputations.) All activities except sports and all sports except football, basketball, or gym were permitted if the child did not wear his prosthesis. In our questionnaire we failed to consider whether the child attended a hospital school, special school or room, or a regular school. Moreover, even in a regular school, there is a difference in activities, so that saying that a child participates in all activities in one school does not necessarily mean that this school has more understanding than others in which the activities are "limited".

Some youngsters in this study are in the Little League or Pony League; however, we have noticed that many of them do not play bimanually. There has been some question as to whether or not these youngsters are as well adjusted as appears on the surface.

One very important fact which was mentioned several times was that these youngsters would like to participate in games for which sides are chosen. In several instances, mention was made that other children did not like to touch the hook, as, for example, in such games as crack the whip and other hand-holding games.

Information based on how the parents thought that their children were accepted by school personnel, children, and neighbors was tabulated and graded as follows:

Above-average acceptance by the school, community, and children implies that the child is well accepted as one of the group. The child is helped toward greater independence, and his situation is often interpreted to others.

Average acceptance implies that the child participates as one of the group in activities.

Below-average acceptance implies rejection from the group and its activities or acceptance only as a handicapped and dependent person. Of the 129 respondents to the question on the attitudes of the principals and teachers, 51 specified above-average acceptance; 74 specified average acceptance; and 4 specified below-average acceptance. Of the 132 respondents concerning the attitude of the school children, 37 specified above-average acceptance; 91 specified average acceptance; and 4 specified below-average acceptance. Of the 138 respondents to the question of attitudes of neighbors and friends, 35 specified above-average acceptance; 96 specified average acceptance; and 7 specified below-average acceptance. It is interesting to note that of the 15 children who were reported to have below-average acceptance (all types of amputation), 7 had amputations below the elbow; 3 had amputations below the knee; 2 had amputations above the knee; 2 had amputations above the elbow; and 1 had multiple amputations. Apparently, the child with amputation below the elbow seems to have the most difficulty in social acceptance.

Several parents said that their youngsters did not wear their prostheses

during play for fear of hurting themselves or others. Instances in which children with prostheses accidentally hurt themselves or others have been rare, and the injuries were no more than minor bruises. Deliberate use of a prosthesis as a weapon has rarely occurred. Nose-pinching with the hook terminal device has caused parents of playmates concern and has definitely impeded the amputee's acceptance. It is wise for children with upper-extremity amputations not to wear their prostheses in body-contact sports or games.

Several parents and amputees brought out the problem of finding jobs. Many told of successful job placement and job accomplishments, household care, and care of babies. It is especially important that prospective employers be reached so that when the patient becomes employable, a job suitable to his training and ability is open to him, since our ultimate goal is a well adjusted, independent individual. The Division of Vocational Rehabilitation is active in this area, and several amputees in this study had had, or were having, job training or higher education through this agency. Besides governmental activities in this field there are many voluntary agencies and fraternal clubs active in this work.

SUMMARY

Although this questionnaire did not cover the various facets of rehabilitation as well as had been hoped for, it revealed some interesting findings.

Greater stress should be placed on prevention, since the largest number of amputations were on a traumatic basis.

Definite conclusions could not be made about surgical treatment. However, the need for further study of growth patterns was definitely indicated. It was noted that although the greatest number of revisions were in the children with amputations below the knee, most of these were done for the acquired amputations due to trauma, malignant growth, and disease; very few revisions were done in the below-the-knee conversion amputations of congenitally anomalous lower extremities.

After the necessary surgery, aftercare of the stump is very important. Physical therapy to maintain, or obtain, full range of motion in the remaining joints is often started before surgery. Bandaging the stump to reduce induration and edema and to shape the stump is recommended. This study reveals the need to stress and to review instructions in stump hygiene with the patient and parents.

More investigation is needed as to the age when a child should be fitted with a prosthesis and the age when training should begin. Most physicians associated with amputee services recommend that a prosthesis be fitted at the earliest possible age, providing that the child is physically, emotionally, socially, and mentally ready. All agree that when a child with a lower-extremity amputation is ready to walk, he is ready for a prosthesis. If the amputation is acquired, the youngster should be fitted with a prosthesis as soon as the stump is in good condition.

There seems to be no universal agreement as to what is the earliest possible age for an upper-extremity prosthesis to be fitted. Passive prostheses have been put on children at about 4 to 6 months of age to teach them to hold or push an object against the normal hand and gross grasping, such as holding a nursing bottle; to have the child become accustomed to the added length of the stump; to encourage the youngster to tolerate an appliance; and to help in functional activities. Recommendations for fitting with a prosthesis depend on the child's development rather than his age.

Further investigation of the influence of the hand which is dominant seemed to be indicated.

The child with amputation above the elbow is as good a prosthesis wearer and user, within the limits of his increased handicap, as the child with below-the-elbow amputations.

The fitting of children with upper-extremity amputations with a hand terminal device did not improve their adjustment to the prosthesis. It has been our experience, with rare exception, that the anticipation of getting a hand is greater than the realization.

Children with lower-extremity amputations and those with traumatic amputations below the elbow wore their prostheses whether or not they had had training. However, training was very important to the adjustment to the prosthesis of the child with amputations above the elbow. Children with congenital below-the-elbow amputations were the poorest prosthesis wearers. This is not meant to imply that training is not important to all groups. Rather, it points out that some types of amputees find their prosthesis helpful to them whether or not they have had training. The initial preparation did not seem to be adequate for children with congenital below-the-elbow amputations. Perhaps they need a different approach or a different method of training. It may be that earlier fitting with a prosthesis, as is now done, may resolve this problem. It was definitely found that this group of children showed the best results when fitted with a prosthesis before they were 5 years of age.

The child's evaluation of himself, his parents' evaluation, and the attitude of the whole population were brought out repeatedly in these questionnaires as being very important factors in his rehabilitation.

The study also revealed the need for greater dissemination of the available information to the many disciplines concerned with the rehabilitation of the child amputee.

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It would be difficult to list individually the many persons of various disciplines who were helpful, not only with the questionnaire, but also with our criteria, but we would especially like to express our appreciation to Dr. Sidney Fishman, Project Director, and other staff members of the Prosthetic Devices Study, Research Division, New York University, College of Engineering, Research Division. We also wish to express our appreciation to other personnel of the University of Illinois Research and Educational Hospitals and Clinics and of this Division for their assistance with this study.

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APPENDIX

UNIVERSITY OF ILLINOIS
DIVISION OF SERVICES FOR CRIPPLED CHILDREN
1105 South Sixth Street
Springfield, Illinois

ARTIFICIAL LIMB STUDY

NAME .....BIRTHDATE.....CASE NUMBER.....

ADDRESS .....
(Street) (City) (County)

1. (a) What part or parts of the body are involved?

Right arm: Above elbow..... Below elbow.....

Left arm: Above elbow..... Below elbow.....

Right leg: Above knee..... Below knee.....

Left leg: Above knee..... Below knee.....

(b) What was the cause of the amputation:

(1) Born that way.....

(2) Accident ..... What kind? .....

(3) Disease ..... What? .....

(4) Tumor or growth .....

(c) Was an operation necessary before getting the limb(s)?.....

2. (a) At what age was your child fitted with his first limb? .....

(b) Did you or another agency buy a limb for your child before he was referred to this Division? Yes..... No..... Name of agency? .....

(c) If (b) was answered "yes", who prescribed that limb? .....

(d) Did he have any training in the use of the limb at that time? Yes..... No.....

If "Yes", where did he get the training? .....

3. Who referred your child to the Division of Services for Crippled Children? (Circle)

(a) Your family physician?

(b) Your public health nurse?

(c) A limb manufacturing company?

(d) Someone else? Who? .....

4. (a) Did you understand what the doctor and other clinic staff said to you and your child at the clinic? Yes..... No.....

(b) Did you need more time at the clinic? Yes..... No.....

(c) How do you think the clinic staff might have been more helpful to you in understanding your child's needs? .....

5. Did your child accept the idea of being fitted with a limb? Yes..... No.....

If he didn't:

(a) Did you discuss this with the clinic staff? Yes..... No.....

(b) What did you do to help your child's attitude toward getting the limb?

6. (a) How old was your child when he was fitted with a limb by this Division? .....

(b) After your child was fitted with this limb:

(1) Did he have any training in its use? Yes..... No.....

(2) If he had training, where did he get it? .....

(3) Do you feel it would have been helpful if he had more training? Yes..... No.....

If yes, why? .....

(4) What instructions were you given on the care of the stump?.....

7. (a) How many hours a day does your child wear the artificial limb(s)? (Circle)

(1) 1 hour (2) 2 hours (3) 3-4 hours (4) 5-8 hours (5) All day

(b) If he attends school, does he wear the limb at school? Yes..... No.....

(c) Is he permitted to wear it in all school activities? Yes..... No.....

If no, in what activities is he not permitted to participate? .....

If no, in what activities does he participate but is not permitted to wear the limb?

(d) If not worn routinely, why? (Circle those that apply) Because of:
(1) cosmetic appearance (2) pain in stump (3) poor fit of socket (4) it is not permitted in school (5) skin irritation of stump (6) Other reasons (state).....

(e) What is the attitude of the principal and teachers? .....

(f) What is the attitude of the school children? .....

(g) What is the attitude of neighbors and friends? .....

(h) Does he like to play with other children? Yes..... No.....

(i) Does he prefer to stay at home? Yes..... No.....

8. If your child was fitted with an arm and hook prosthesis:

(a) List activities he does with its help.

(1) Dressing and personal care (Examples: opening toothpaste tubes, pulling on socks, lacing shoes.)

(2) Eating (Examples: use of knife and fork, use of bottle or can opener.)

(3) Work (Examples: hammering nails, using spray gun, putting clips on paper, carrying three or more packages.)

(4) Social (Examples: wearing of hook or hand to various social activities, opening wallet or purse.)

(b) Which of these you listed is he able to do without the hook? (List)

(c) Does he do these faster with the hook? Yes..... No..... Sometimes.....

9. If your child has an artificial hand as well as a hook:

(a) How many hours a day does he wear the hook? .....

(b) How many hours a day does he wear the hand? .....

(c) Does he wear the hand only for dress occasions such as church, parties, etc.?

Yes..... No.....

10. (a) Have you purchased another limb since the Division made one available?

Yes..... No..... When?..... Why?.....

(b) Have you purchased extra parts for the original limb? Yes..... No.....

If "yes", what? .....

(c) If you changed to another limb, give reasons why? .....

(1) Is present limb: (Check or circle)

a. Better than b. As good as c. Not as good as original

11. How often does your child return to clinic for re-check examinations? (Circle)

(a) Every 3 months (b) Every 6 months (c) Every 9 months (d) Every year (e) Over a year

12. How often has the limb required repair or adjustment for length?

(a) Every 3 months (b) Every 6 months (c) Every 9 months (d) Every year (e) Over a year

13. If your child has had his first limb replaced, how long did the first limb remain satisfactory?

(Circle) (a) 1 year (b) 2 years (c) 3 years (d) Other (state) .....

14. How do you think we can be more helpful to children like yours?

The Effect of Particle Size of the Heterogenous-Bone Transplant on the Host-Tissue Vascular Penetration*†

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The literature on experimental grafting is extensive, but only a few contributions have been concerned with the vascular pattern which is an inherent part of the response of the host tissue to transplanted bone. The ability of the bone transplant to accept neovascularization from the host bed has not been studied until recently. Functioning blood vessels in grafts of embryonic and autogenous bone have been reported to be present as early as five hours and up to eleven days after grafting [1,3,4,7,10]. Studies on experimental transplants of homogenous bone have shown that vascularization occurs between four and twelve weeks [5,6,11]. Stringa reported a comprehensive study in which large grafts of autogenous, homogenous, and heterogenous bone of the cortical and cancellous type were placed in the femoral medullary cavity and under the renal capsule of rabbits. Stringa concluded that the vascular penetration of the heterograft was approximately six times slower than the vascularization of the autograft.

Variations in these reported experimental results may be due to several factors: the different types of bone tested, the size of the transplant, and the type of host bed. Furthermore, it should be recognized that the process of revascularization in bone transplants cannot be well documented on the basis of histological sections alone.

We have therefore undertaken a study of the process of vascularization of heterografts of calf bone after implantation in the anterior chamber of the rat's eye, analyzing injected and cleared specimens by means of stereomicroscopy. The grafts were prepared as a single large fragment or as a conglomerate of small particles in the form of a paste. The anterior chamber of the rat's eye was chosen as the host bed for implantation because the implanted bone could be observed clearly, and the vascular response of the host tissue readily delineated by dye injection.

METHOD

Adult albino rats of the Long-Evans strain were used. The following categories of implantation material were tested:

1. Calf bone prepared as large fragments and averaging 2.8 millimeters in length, one millimeter in width, and one millimeter in depth, which had been stored from six weeks up to nine months at 4 degrees centigrade in bovine plasma or physiological saline solution. This bone was of three types: three-month-old calf cortical bone, calf cancellous bone, and fetal cortical bone.

2. A calf-bone paste composed of many small particles, varying from 0.3 to 0.7 millimeter in diameter and treated with bovine plasma in the same fashion as the large fragments of calf bone [9].

3. "Fresh" cortical and cancellous calf bone of large-fragment size (average

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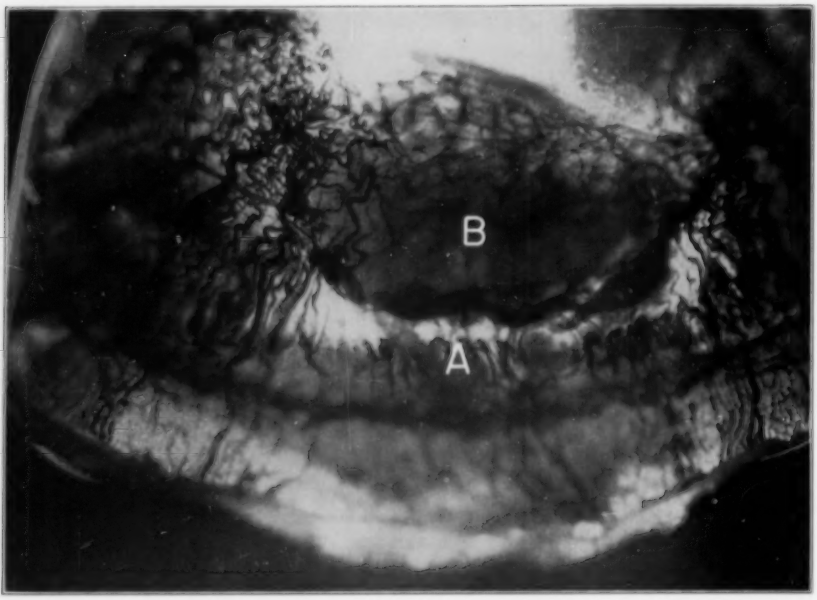

FIG. 1-A

Photograph of an implant of autogenous cancellous bone in the anterior chamber of the rat's eye at one week. The bone lies in the corneal-scleral angle adjacent to the choroid body. A sinusoidal network of vessels, originating in the iris, *A*, is situated at the edge of the implant, *B*, with smaller, divergent branches penetrating most of the bone. Not all the vessels can be clearly seen in this two-dimensional photograph (× 27.5).

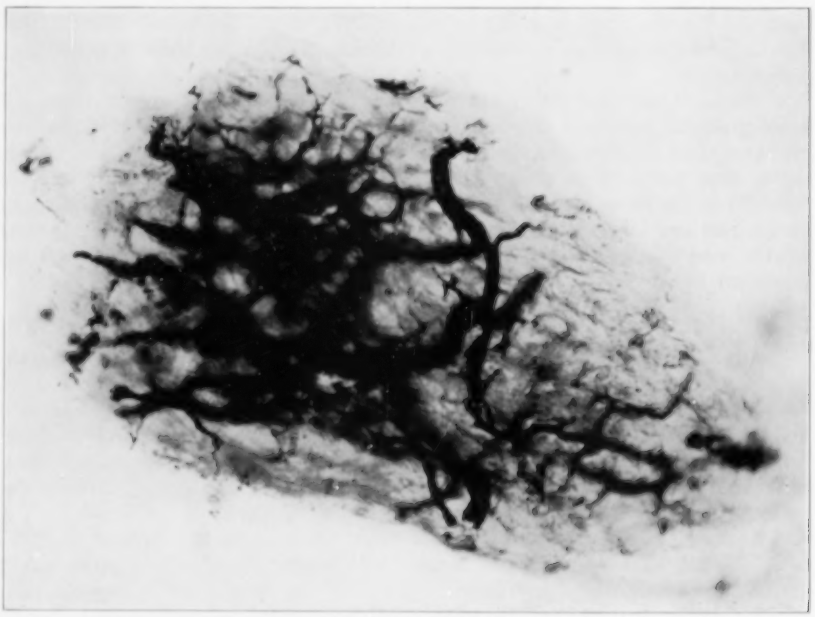

FIG. 1-B

Photograph of the vascularization of an implant of autogenous cancellous bone dissected from the eye one week after implantation. All surface vessels have been removed. Deep penetrating vessels enter the major portion of the bone (× 73).

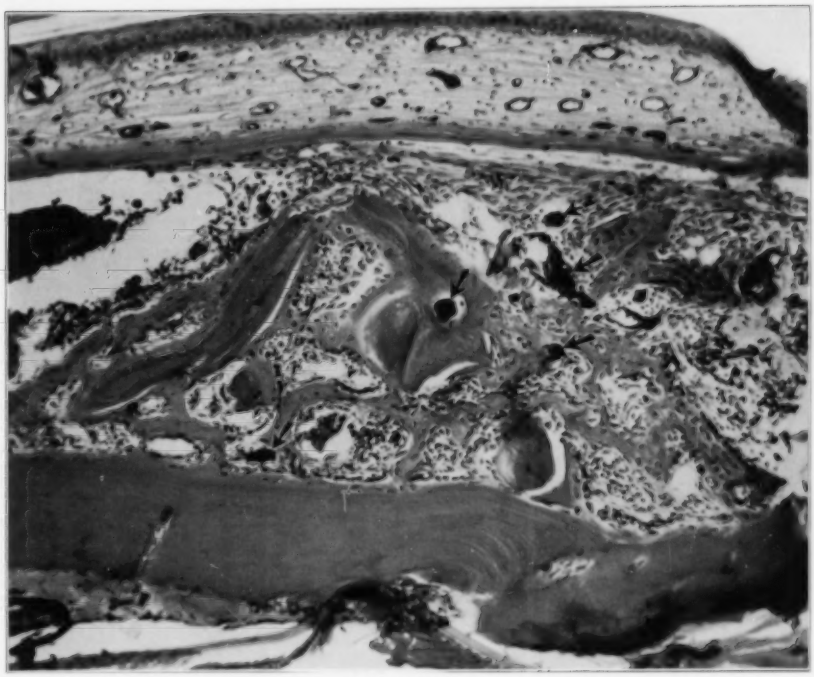

FIG. 1-C

Photomicrograph of a serial section of an implant of autogenous cancellous bone at one week. The injected host vessels, indicated by arrows, are located primarily in the trabecular pattern of the new bone. One vessel occupies an open Haversian canal of an acellular area of donor bone. The cornea is at the top of the photomicrograph (× 145).

size, 2.8 by one by one millimeter). The "fresh" specimens could not be implanted until the second day after removal from the calf because of technical difficulties in transportation to the laboratory.

4. Fresh autogenous cancellous bone of large-fragment size (average size, 2.8 by one by one millimeter) obtained from the iliac crest of the rat under sterile technique.

All samples of preserved calf bone and calf-bone paste were prepared under rigid aseptic technique according to the method of Tucker and were supplied to us by the Squibb Institute for Medical Research. "Fresh" samples of sterile bovine bone were supplied by Dr. E. J. Tucker. The periosteum was removed from all large specimens. The large fragments were cut to size from the stock samples with a rongeur and an osteotome. The bone paste was used directly from the sterile disposable plastic syringes in which it was received. The size of the large fragments and the particles in the paste were determined by direct measurements on a calibrated scale.

Histological examination and tissue culture of samples of the calf bone before implantation in the anterior chamber of the rat's eye demonstrated no apparent living cells. Since autogenous cancellous bone is generally accepted as the ideal type of clinical graft, it alone was selected as the control tissue to be used for the comparison of the initiation and degree of vascular penetration in autogenous bone with the vascular penetration in the various types of heterografts. In this series of experiments the control tissue was of large-fragment size only. A further series of experiments are now in progress in which the control tissue will include pastes of both cortical and cancellous fresh autogenous bone.

Before implantation, the large bone fragments were removed from the vials

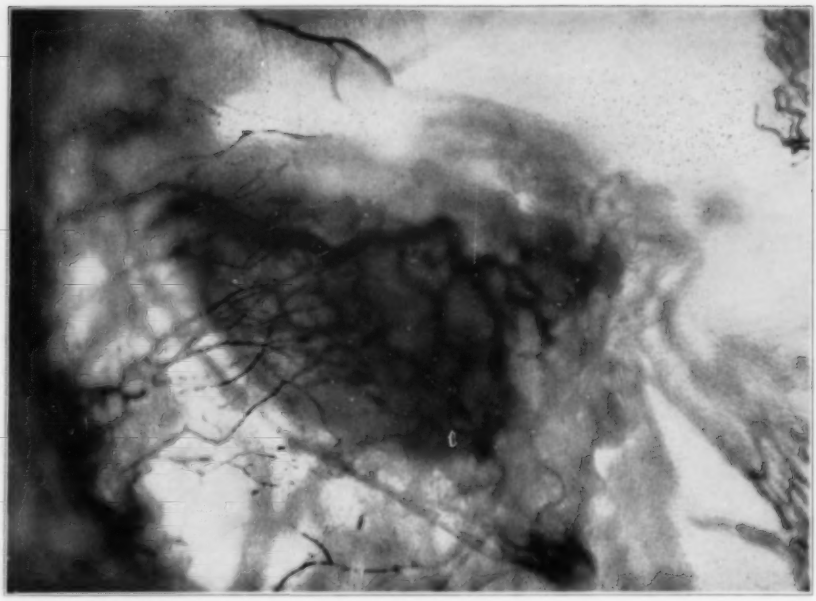

FIG. 2-A

Implant of autogenous cancellous bone in the anterior chamber of the eye at six weeks, which demonstrates vascular penetration of all aspects of the bone by numerous diverging vessels arising from a single major vessel of the iris. This finding is exceptional in that the implant is usually vascularized by several penetrating vessels of the iris (× 31).

in which they had been preserved and placed in a sterile Petri dish in a few drops of Hanks balanced salt solution containing 100 units of penicillin and 100 gamma of streptomycin per milliliter. With the animal under anesthesia, the pupil of the eye was dilated with 5 per cent homotropine in 1:10,000 zephiran solution. The bone was implanted through a small corneal incision, either as a single large fragment or as a conglomerate paste consisting of as many small fragments as could be accommodated, in the corneal-scleral angle opposite the incision in the cornea. Extreme caution was taken to avoid contamination during the implantation. Cultures of material aspirated from sample implanted eyes were sterile in every instance.

Bone of the same category was implanted into both eyes of each of the rats used. In each category of implant at least one and usually two animals (or two or four eyes) were sacrificed at intervals of one, two, three, four, six, eight, ten, fifteen, and twenty weeks. The technique described by Trueta and Harrison was employed to outline the vascular patterns characteristic of each bone implant. At the time of sacrifice the chest of the rat was opened while the animal was anesthetized, and approximately forty milliliters of 2 per cent Berlin blue solution * was injected intracardially while the heart was still beating. This particular dye adequately defined the vascular pattern in the anterior chamber of the eye, and we, like Trueta and Harrison, found it to be superior to other injectable materials. After completion of the injection the eye was extirpated, fixed in 10 per cent neutral formalin, and then rendered transparent by the Spalteholz technique. The specimens were studied under the stereoscopic microscope after clearing. Observations were confined chiefly to the relationship of the host blood supply to the anterior and posterior aspects of the graft which were adjacent to

* Berlin blue (Prussian blue soluble): Hopkins & Williams, Ltd., Freshwater Road, Chadwell Heath, Essex, England.

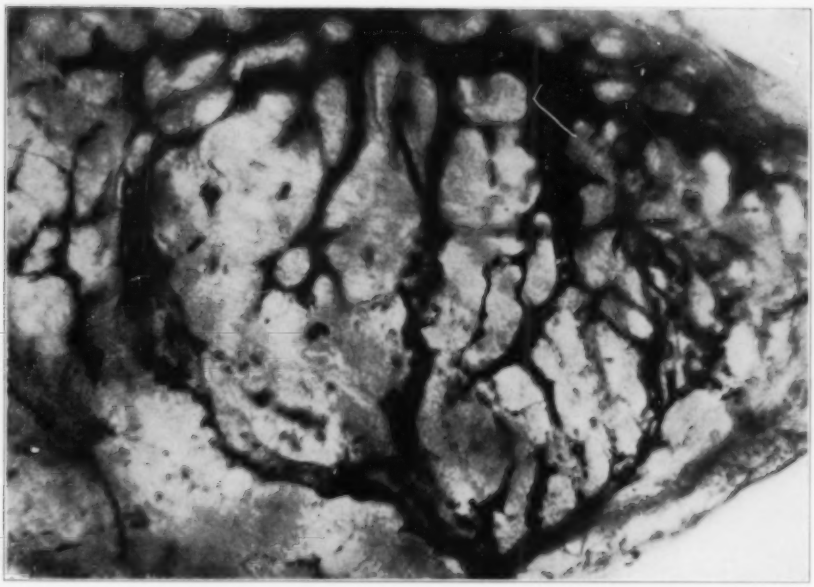

FIG. 2-B

Photograph of an implant of autogenous cancellous bone at eight weeks, from which all surface vessels have been removed. The degree of deep penetration of the bone is evident (× 145).

the cornea and iris respectively. In order to photograph these vascular patterns it was necessary to remove the posterior segment of the eye and dissect out the lens from the anterior chamber, thereby exposing the bone implant in its surrounding environment of iris, choroid body, and cornea. In many instances the implant itself was removed from the eye, and blood vessels lying on its surface were vigorously scraped away in order to verify the existence of vessels penetrating deeply into the bone.

Of the 121 implantations performed, twenty-one were of autogenous bone, seventy-two were of heterogenous bone of large-fragment size, and twenty-eight were of paste of heterogenous bone.

RESULTS

Autogenous Cancellous Bone

One week after implantation the autograft was adherent to the choroid body and iris and was enclosed by a film of connective tissue. The blood vessels attacking the bone arose from the iris in a fairly uniform manner. Although the majority of the vessels extended only to the surfaces of the graft, a number of them penetrated deeply into the substance of the graft. A dense vascular network was seen at the edge of the implant, which was in contact with the iris. This network consisted of numerous small divergent vessels which extended into most of the deeper portions of the implant (Figs. 1-A, 1-B, and 1-C).

The degree of penetration increased with time, and all surfaces of the graft appeared to be thoroughly penetrated by six weeks, at which time there was no longer any tendency to marginal concentration of vessels at the base of the implant (Figs. 2-A and 2-B). Usually, no single blood vessel appeared responsible for the major blood supply. The vessels covering both the anterior and posterior surfaces of the bone exhibited anastomoses.

Examination of histological sections revealed injected vessels extending into the trabecular pattern of both the donor bone and new bone. Vascular penetration

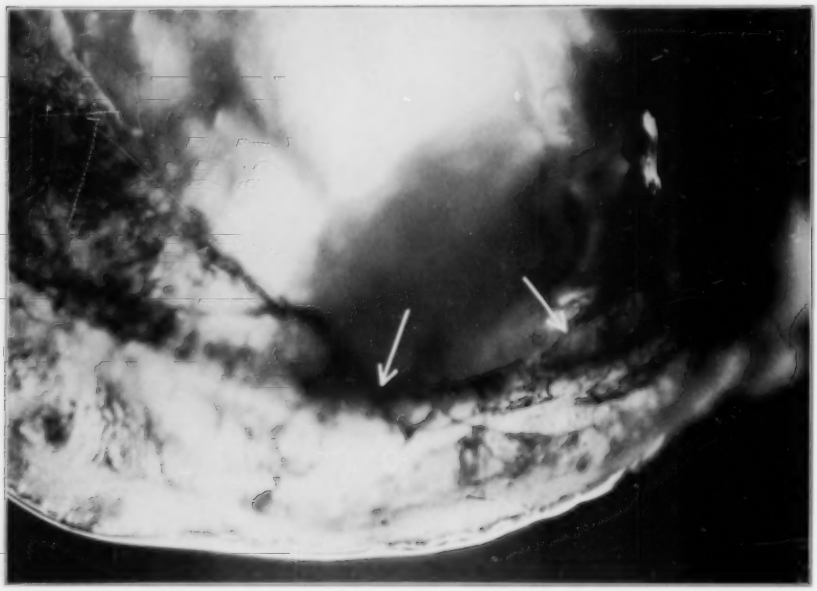

FIG. 3

Photograph of an implant of heterogenous cortical calf bone of large-fragment size one week after implantation in the anterior chamber of the rat's eye. There is a vascular concentration where the bone is in contact with the iris (arrows), but no advancing surface vessels or deep penetration is noted (× 27.5).

of a Haversian canal in the implant was rarely observed (Fig. 1-C). The penetrating vessels were sinuous, seeming to adapt themselves to the shape of the trabeculae.

Heterogenous Calf Bone

Large-Fragment Size

The vascular pattern of all types of heterogenous implants of large-fragment size was similar, irrespective of the type of bone and method of preservation. Furthermore, the vascularization of "fresh" heterogenous-bone grafts did not appear to differ materially from bone which had been preserved in plasma or saline solution.

At the end of one week a large bone fragment was usually adherent to the iris and, in some instances, was adherent to the cornea. Very little vascular response was apparent at this stage. In some implants, the vessels of the iris tended to concentrate around the edges of the bone adherent to the iris (Fig. 3). Occasionally, a single vessel arising in the iris could be seen to project over a limited portion of the posterior surface of the bone. Fine capillary extensions of the marginal corneal vessels could also be seen to extend toward the apex of the cornea. These vessels were usually limited to that part of the cornea covering the graft, although in no instance was there observed any direct contact of these vessels with the bone.

By the second week, the vessels of the iris were concentrated at the edge of the graft and were enlarged. Numerous capillary-like vessels projected over the posterior surface of the bone, and, in rare instances, a single vessel was found to penetrate the graft, but only for a short distance (Fig. 4).

At the end of the third week, the findings were essentially the same, but the vessels lying on the surfaces of the graft were larger and followed the trabecular pattern of the bone, to which they clung tenaciously when an attempt was made

FIG. 4

Fragment of heterogenous cortical calf bone in the eye at two weeks. Small vessels extending over the surface of the bone from the vascular network at its border (arrows) supply only the periphery of the implant (× 27.5).

to remove them. They appeared to be enveloped in connective tissue which surrounded the bone.

After the fourth week, the vascular reaction assumed a pattern which remained characteristic throughout the subsequent sixteen weeks. The marginal corneal vessels completely disappeared. The vascular network at the edge of the graft, adjacent to the iris, was in most cases dense and sinusoidal. When, as in some instances, a wide area of the bone graft was covered by vessels of large caliber, this pattern was more evident on the posterior than on the anterior surface. Capillary-like branches with blunt ends extended from these surface vessels into the bone, but penetration was limited to a fraction of a millimeter (Figs. 5-A, 5-B, and 5-C).

Small-Particle Size

At one week, vessels of large caliber covered both the "iridic" and "corneal" surfaces of the bone. Numerous vessels of smaller caliber projected into the depths of the conglomerate implant. All specimens at this time revealed an extensive proliferation of the marginal corneal vessels (Fig. 6).

The vascular reaction of the cornea reached its maximum during the second and third weeks and then receded abruptly to completely disappear by the fourth week. The concentration of vessels of the iris around the periphery of the graft was not so evident here as with the large bone fragment. Vessels of the iris projected directly into the depths of the bone paste. The caliber of the individual vessels was shown to have increased in size when compared with that of the earlier sacrifice periods (Fig. 7).

From four weeks to ten weeks the bone continued to show increasing penetration. The vessels increased in size, and, in several instances, the posterior ciliary artery was recognized as the main trunk giving rise to numerous divergent vessels. In those instances in which the bone paste had spread at the time of implantation to separate portions of the eye, bifurcating vessels projected from

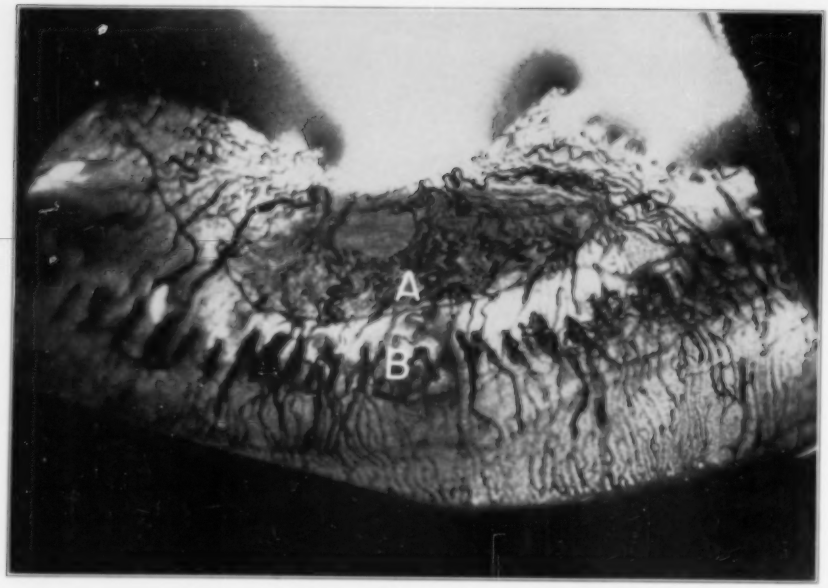

FIG. 5-A

Heterogenous cortical bone of large-fragment size at six weeks. A greater part of the periphery of the "iridic" aspect of the bone is covered by vessels of the iris of large caliber. These vessels have established contact along the margin of the bone, *A*, which lies next to the iris, *B*, without any change in size or evidence of a concentration of sinusoidal vessels (× 27.5).

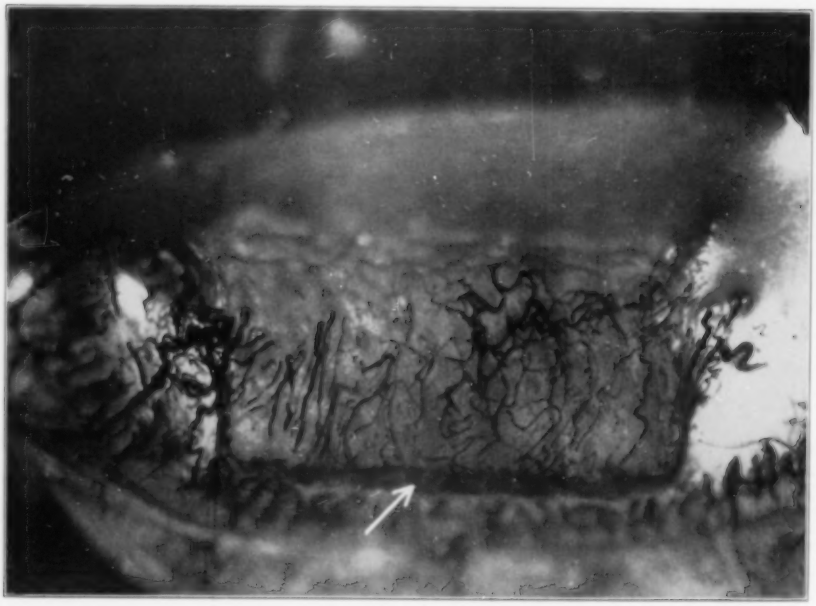

FIG. 5-B

Heterogenous bone of large-fragment size at fifteen weeks. Numerous vessels which arise from the vascular concentration at the base of the graft (arrow) extend over most of the bone surface. The terminal tufts of these vessels penetrate the bone for only a fraction of a millimeter (× 27.5).

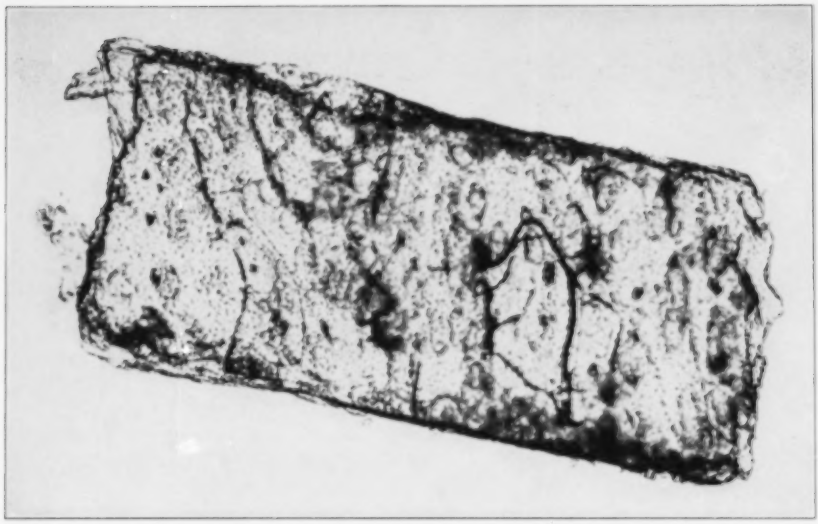

FIG. 5-C

Photograph of specimen in Fig. 5-B from which all surface vessels have been removed (× 38).

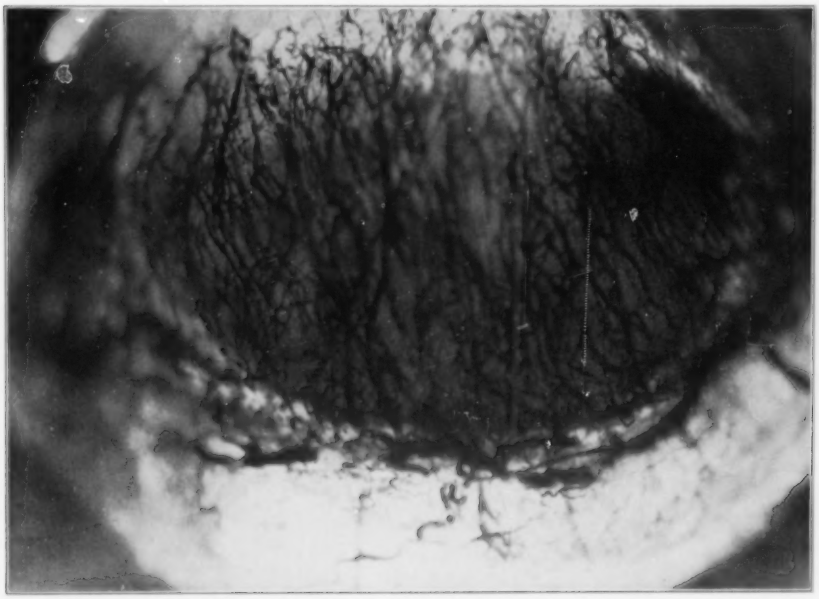

FIG. 6

Paste of heterogenous bone of small-fragment size at one week. The implant is completely obscured by a hypervascularization of the marginal corneal vessels. The specimen is viewed from the "corneal" aspect. These vessels are limited to the area of the cornea overlying the bone implant (× 27.5).

the posterior ciliary artery to each locus of bone (Fig. 8). The vascular elements within the graft had no particular pattern and penetrated all aspects of the implant.

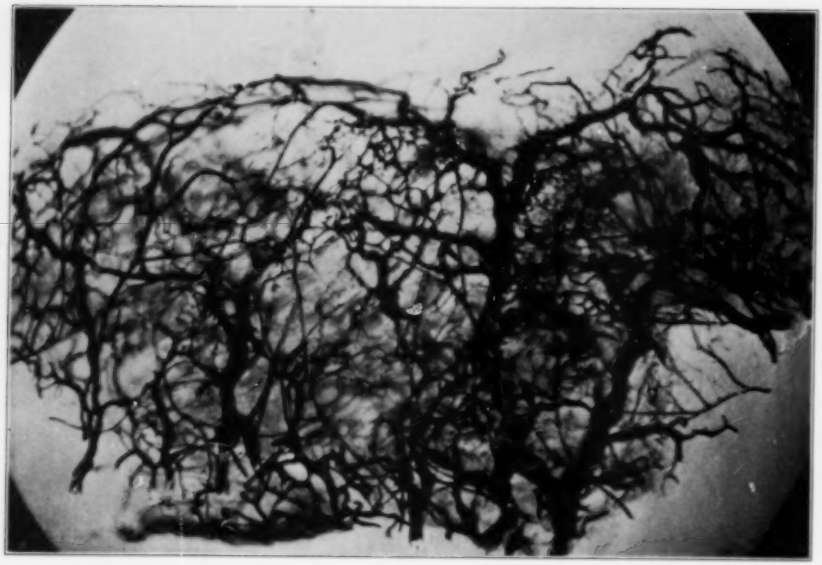

FIG. 7

Heterograft paste at two weeks which has been removed from the anterior chamber of the eye. By this time the small fragments in the paste have become firmly bound together by granulation tissue. All surface vessels have been removed. There is deep and widespread vascularization of the entire implant by several vessels of large caliber and numerous, small, capillary-like vessels (× 58).

FIG. 8

Heterograft paste implanted in two separate areas (arrows) in the anterior chamber of the eye. Numerous vessels from the bifurcating posterior ciliary artery are seen to penetrate the bone implants (× 27.5).

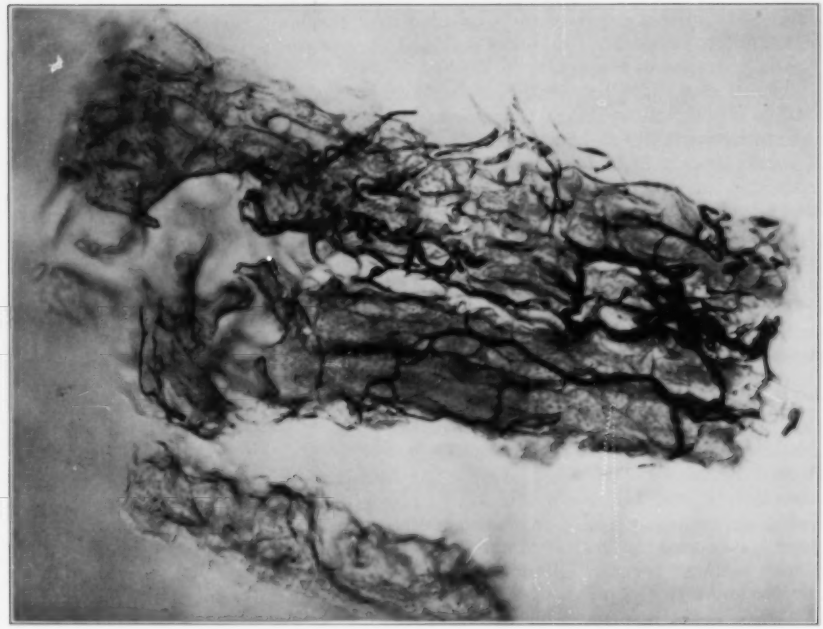

FIG. 9

Heterograft paste at fifteen weeks. The implant has been dissected from the eye, and all surface vessels removed. The degree of penetration has not changed appreciably from that at earlier periods of sacrifice (× 62).

After the tenth week, the vessels became somewhat smaller. However, the degree of penetration of the bone did not change (Fig. 9).

DISCUSSION

In these experiments the region of the iris and the choroid body in the anterior chamber of the eye of the rat proved to be a satisfactory site for the study of the vascular penetration of bone implants from the host tissues. The reaction of the marginal corneal vessels which was observed appears to be the result of the irritation induced by the implanted donor bone.

In some respects, the host vascular penetration of the paste of heterograft bone and of the autograft of large-size cancellous bone was strikingly similar; both types of implants were usually well penetrated by vessels as early as one week, and the pattern was characteristic of unrestricted and rapid vascularization because blood vessels usually arose directly from the iris and thoroughly penetrated the grafts from both the anterior and posterior surfaces without any apparent barrier to entrance.

A comparison of the vascularization of the large heterograft with that of the autograft of large cancellous bone, however, points up striking differences. In contrast to the latter, the large-size heterograft, whether of cancellous or cortical bone, or whether "fresh" or treated in saline solution or in plasma, showed no appreciable deep vascular penetration throughout twenty weeks of these experiments. Furthermore, the vascular pattern observed here suggested obstruction to the penetration of the graft because a dense network of sinusoidal vessels appeared around the periphery of the graft shortly after implantation and persisted throughout twenty weeks. Although numerous vessels of small caliber

emerged from this network and extended over the bone surface, the vascularization remained superficial and was confined almost exclusively to the posterior, or "iridic", surface of the graft.

In its essentials, this study on the vascularization of bone grafts corroborates Stringa's observations that there is rapid and thorough vascularization of the autograft, but slow and incomplete vascularization of the large-size heterograft. It would seem only logical to explain the thorough penetration of the heterograft paste and the incomplete penetration of the large-size heterograft as owing in part, at least, to the different spatial arrangements in these two types of grafts. Numerous spaces are present in the bone paste which are immediately available to penetration by host vessels. These conditions do not prevail in the case of the large-size heterograft. One cannot ignore, however, the possibility that chemical or physicochemical mechanisms account for these differences in vascular penetration. Histological data on similar grafts strongly suggest a correlation between the intense host inflammatory reaction provoked by the paste and its rapid and thorough vascular penetration.

Particle size, therefore, appears to be an important factor in the vascularization of the heterograft. The capacity of the paste of heterogenous bone to induce a host vascular response might also be related to its physicochemical properties. It still remains to be determined what influence, if any, this capacity to be vascularized exerts on the potential of a given donor tissue to induce osteogenesis. Our observations, at least in the case of the heterograft, indicate that the phenomenon of vascularization cannot be equated directly with the success or failure of the bone as a graft. Histological data on the host-graft cellular reaction for correlation with the present data will be presented in a future communication.

SUMMARY

The anterior chamber of the eye of the albino rat was found to be well suited as an ectopic site for a visual study of the vascularization of bone-graft material.

The pattern and rate of vascularization of the calf-bone heterografts of large size and small-particle size were studied at intervals throughout twenty weeks. Autogenous cancellous bone was used for comparison, and 121 implantations were performed.

Vascular penetration of the heterograft when it is in the form of a conglomerate paste occurs as rapidly as it does in the cancellous-bone autograft of large-particle size. There appears to be no particular barrier to vascular penetration. Large-size heterografts, on the other hand, do not demonstrate any degree of deep penetration but do show a surface vascularization.

There is no appreciable difference in the host vascular response to various types of calf-bone heterografts of large size, whether they are "fresh" or stored in plasma or saline solution.

NOTE: We wish to acknowledge the helpful criticism of James Dingwall, M.D., Associate Medical Director, Squibb Institute for Medical Research, and Marshall R. Urist, M.D., Associate Clinical Professor of Surgery, Division of Orthopaedic Surgery, University of California School of Medicine at Los Angeles. We also wish to acknowledge the meticulous and excellent work of Miss Pauline Barnes, who prepared the cleared specimens and histological sections, and the technical assistance of Mrs. Indra Michalovskis.

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DISCUSSION

Dr. Marshall R. Urist, Los Angeles, California: In European countries calf bone has been used in place of human-bone grafts for many years. In the era before World War I beef-bone plates and screws were used for bone surgery before stainless steel became available. Recent clinical investigations have renewed interest in beef bone; however, if we are to return to the use of heterogenous materials, it is important that a study such as this one by Anderson, Schmidt, and LeCocq be done very well. They have done a significant amount of work—121 implantations in the anterior chamber of the rat's eye. Their experiments are comparable with those performed by Stringa, who placed the implants beneath the renal capsule. By using the eye, Anderson, Schmidt, and LeCocq have obtained better visualization of the host vascular response. What is the host vascular response? This is the capacity of the host to make new blood vessels upon the surface and within the substance of the implant. The host vascular response is an integral component of inflammation caused by the presence of the implant.

Does the vascular response influence osteogenesis? Anderson, Schmidt, and LeCocq found the same amount of vascular reaction in response to the heterograft, which does not produce new bone in the eye, as to the autograft, which does produce bone in the eye. What determines the magnitude of the vascular response? The authors observed that with implants of small-particle size and consequent large surface area, the volume of blood vessels formed in the inflammatory response of the host was greater.

What determines the depth of penetration of the implant by the host blood vessels? The authors' observations suggest that the host forms a network of blood vessels on the surface of all implants but relatively few of these vessels penetrate if the implant is composed of particles of large size, regardless of whether it is autogenous or heterogenous. However, when the implant consists of autogenous cancellous bone, even though the particle size is large, there is a high degree of penetration, as would be expected. Anderson and his associates found that if the surface areas of the heterogenous-bone implants were increased, the vascular response to these was as great as it was to the autografts. We would like to know if the host makes end-to-end anastomosis with the vessels in an autograft.

What is the relationship between the antigenicity of the transplant and the host vascular response? In these histological sections we are accustomed to estimate the antigenicity of the donor tissue on the basis of the number of lymphocytes, plasma cells, and reticulocytes in the inflammatory response of the host. I will ask Dr. Anderson if an inflammatory barrier was observed around the implants of heterogenous bone, and, if so, did this contain plasma cells, lymphocytes, and reticulocytes. Anderson and his associates found that the implants of autogenous bone of large-particle size rarely caused a vascular reaction in the cornea, whereas implants of homogenous or heterogenous bone often did. The vascular penetration of the implant of autogenous bone of large-particle size was apparent in one week, whereas in the implant of heterogenous bone of large-particle size more than twenty weeks was required for this to occur.

Is the vascular response related to the failure or success of a true bone-grafting operation? I think that this is a question to which we all want to know the answer, and we all are trying to devise the perfect experiment to answer this question. In their manuscript the authors state that the host vascular response occurs regardless of the osteogenetic potency in a graft. To some extent this makes sense, because, as you all know, if the host bed consists of good bone, if the transplant has complete contact with the host bone, if there is no gap to bridge, and if there is a physiological amount of compression, implants of homogenous bone or heterogenous bone will succeed as well as grafts of autogenous bone do. In the most successful bone-grafting operations, it appears that the implant serves mainly as an absorbable form of internal fixation. Even a graft of autogenous bone is generally inadequate in an adult if there is a large gap to bridge and if the contact with a host bed is insufficient.

So far as they have gone with this study the authors have demonstrated that the vascular response is a secondary phenomenon in relation to the process of osteogenesis. It is necessary that they carry their experiments further to correlate the host vascular pattern with histochemical, histological, and immunological studies. In this connection, I found that the authors had made progress in this direction when I visited their laboratory in Seattle six months ago.

Nearly all previous observers of the vascular response concluded that grafts of autogenous bone were penetrated by new blood vessels six to twenty times faster than were grafts of homogenous or of heterogenous bone. Anderson and his associates claim that this conclusion needs to be

modified to include the influence of the surface area because the penetration is greatly increased in implants with a large surface area.

DR. ANDERSON (closing): We were fortunate in having Dr. Urist visit us. His helpful criticisms of this work have helped to determine the manner in which this study has been conducted. It appears to me that Dr. Urist has answered many of his own questions; he leaves only two for me to answer.

One concerns end-to-end anastomoses between the host vessels and the vessels in the implant or the graft. We have not observed these. From the cleared specimens, which do not permit completely accurate observations, we believe that the vessels observed do not follow the old Haversian systems. Similar observations were made on microscopic sections.

The other question that Dr. Urist brings up concerns the presence of an inflammatory barrier around the graft of heterogenous bone. From our observations, the inflammatory reaction which occurred around the grafts of heterogenous bone of large-particle size in the eye was relatively small compared with that around the grafts of heterogenous bone of small-particle size.

Electromyographic Analysis of the Function of the Muscles Acting on the Ankle during Weight-Bearing with Special Reference to the Triceps Surae*

BY S. J. HOUTZ, M.S., AND FRANK P. WALSH, M.D., DETROIT, MICHIGAN

From the Detroit Orthopaedic Clinic, Detroit

During the past two years the staff at the Detroit Orthopaedic Clinic has endeavored to make objective evaluations of patients who needed or have had operative procedures to alleviate muscle imbalance in the leg and foot. One phase of this study was concerned with the calcaneus foot, a deformity caused by paralysis of the triceps surae after poliomyelitis.

In the course of this investigation it became evident that there was a lack of understanding of the function during weight-bearing of the normal muscles which act on the ankle. Theories concerning the function of the gastrocnemius and soleus muscles have often caused confusion about what these muscles actually do. It is relatively unimportant to assign specific duties to certain muscles during normal activity because, in general, they function with others in associated patterns. In pathological conditions, however, one is cognizant of the need for understanding of muscle function.

The action of the gastrocnemius on the knee has rarely received consideration, yet loss of its function as the result of poliomyelitis often causes hyperextension of the knee joint. This function of the gastrocnemius in preventing hyperextension of the knee has been observed repeatedly in the clinical evaluation of patients with paralysis after poliomyelitis and has also been mentioned by Wright. Genu recurvatum does not occur when the knee flexors, the hamstrings, are paralyzed. Jones demonstrated that during the growth periods the heads of the gastrocnemius migrate proximally on the distal portion of the shaft of the femur. In the fetus the gastrocnemius attaches to the epiphyses of the femur. During the child's transition from crawling to toddling and then to erect walking, the gastrocnemius eventually attains an attachment wholly above the epiphyseal line on the posterior surface of the femur. In the erect position the gastrocnemius then passes backward from the metaphyseal region of the femur over the condyles and downward to its insertion on the calcaneus. In this way the force of its contraction is applied to the femur at a greater angle, rendering the gastrocnemius more efficient as a stabilizer of the knee and preventing hyperextension in the erect position [22]. A perpendicular line dropped from the center of gravity falls anterior to the axis of the knee joint, and thus gravity favors extension of the knees. To counteract this force, the flexors are normally active during standing [22]. These phenomena suggest that the gastrocnemius plays a role in the function of the knee.

The action of the triceps surae at the ankle is well known. Mechanically, it is stretched beyond its resting length during weight-bearing when the foot moves from the relaxed free position of about 30 degrees of plantar flexion to a right angle. This stretching decreases the slack in the tendon which the muscle must overcome to produce movement of the ankle. Jones stressed an important concept which was presented previously by Ellis regarding muscle contraction in the

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weight-bearing appendages. In this concept it is pointed out that the moving ends of the extrinsic muscles of the leg and foot are reversed from the traditional designation of the origin and insertion as the fixed and movable points of attachment respectively. Thus, with the foot firmly planted on the ground the insertion is the stationary attachment around which the tibia and fibula are moved. Joseph and Nightingale [12] and Smith [21] showed that the gastrocnemius and soleus are important muscles in maintaining the upright posture. The extensive work on human locomotion done by the group at the University of California [23] and by others [1,2,17,19] demonstrated that the calf muscles are active also in raising the heel from the ground.

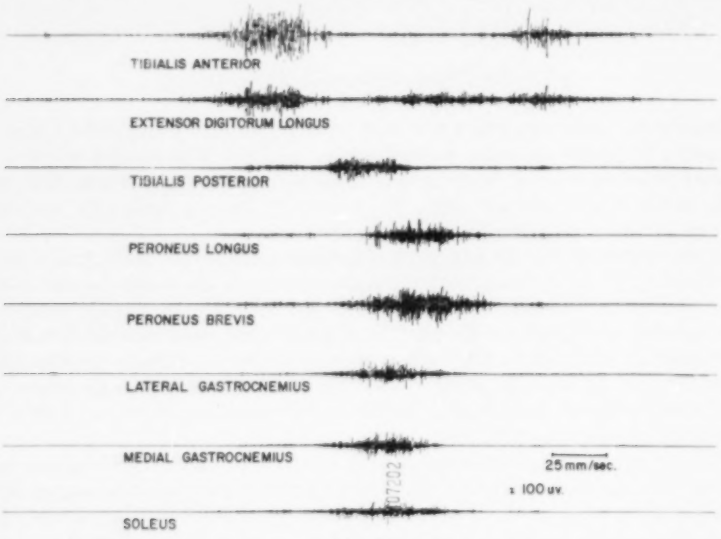

FIG. 1

Sequence of muscle action during a continuous movement from maximum dorsiflexion to maximum plantar flexion in inversion, followed by a return to maximum dorsiflexion in eversion. Contraction of the toe flexors was differentiated from the other muscles by virtue of the fact that action potentials commenced simultaneously with the activity in the toe extensors, gradually increasing in magnitude to reach peak activity at the same time maximum contraction was elicited in the peroneus longus. Thereafter, action potentials of the toe flexors diminished sharply, but low voltage activity was recorded throughout the remainder of the cycle.

The role that the triceps surae plays in the function of the longitudinal arch of the foot has been either the subject of controversy or ignored [5,13,16,20]. The investigator who studies the foot of a cadaver or of an adult and finds close-fitting joints with curved surfaces, wedge-shaped bones, and taut, non-pliable ligaments is inclined to stress the importance of the architectural structure of the foot and disregard the influence of muscle function. In children the importance of muscle function is more obvious. It is well known that paralysis of the gastrocnemius and soleus muscles presents a serious problem, owing to the development of a progressive deformity of the foot in which the calcaneus is rotated into the vertical position. Although a completely flail foot usually is not deformed, the presence of no more than the intrinsic muscles results in a calcaneocavus deformity. The triceps surae, acting through the tendon of Achilles, is the only muscle in a position to counteract the direct pull on the calcaneus of the intrinsic muscles and taut plantar fascia and the indirect pull of all the sling muscles supporting the arch and fore part of the foot [10]. Emmel and LeCocq believed that the tension of the tendon of Achilles on the calcaneal epiphysis is so important in children that

they advocated transplanting the hamstrings to this tendon when the gastrocnemius and soleus are paralyzed.

During relaxed standing, the center of gravity, when projected downward, oscillates around the geometric center of the supporting base—the area formed by the two feet and space between them [6,7,14]. These oscillations are greater in the anteroposterior than in the side-to-side planes. The pattern of oscillation remains relatively constant for any one person regardless of changes in the alignment of the superstructure, since the posture assumed automatically compensates for any functional or pathological asymmetry [4,8,9].

A mechanical analysis of the lower extremity during standing shows: (1) that the weight-bearing axis of the calcaneus is 1.0 to 1.5 centimeters lateral to that of the tibia [18]; (2) that the longitudinal axes of the tibia and femur form an angle of approximately 170 degrees at the knee; and (3) that the distance between the geometrical centers of the femoral heads is greater than that between the geometrical centers of the knees in the position of normal stance [22]. Because of the asymmetry of these weight-bearing axes, caused by the lateral placement of the calcaneus in relation to the vertical tibia and the obliquity of the femur in relation to the tibia, greater tension stress is sustained by the muscles, ligaments, and tendons on the medial surface of the ankle and knee joints than by those on the lateral side [18,22]. Thus, it might be anticipated that the activity of the muscles crossing the medial aspect of the knee and ankle would be greater than that of the muscles crossing the lateral aspect of these joints.

The purpose of this study is to present electromyographic evidence concerning the function of the normal muscles acting on the ankle during weight-bearing, with emphasis on the function of the triceps surae, and to attempt to correlate these findings with clinical observations.

MATERIAL AND METHODS

The subjects of the investigation were three male and seven female healthy young adults, ranging in age from sixteen to eighteen years, except for one woman twenty-three years old. All were athletic in build, had a minimum amount of adipose tissue and had clinically normal feet. Two series of observations were performed on three subjects; single studies were carried out on the others.

Muscle action potentials were picked up and, after appropriate amplification, were recorded on an eight-channel Offner dynograph. Prior to each experiment, the electromyograph was calibrated with the same setting of amplification for all recordings and for all channels. The following muscles were sampled: tibialis anterior (T.A.), extensor digitorum longus (E.D.L.), medial and lateral heads of the gastrocnemius (M.G. and L.G.) and soleus (M.S. and L.S.), peroneus longus and brevis (P.L. and P.B.), and flexor digitorum longus (F.D.L.). A few experiments also included an investigation of the thigh muscles along with the gastrocnemius and tibialis anterior.

All activities were performed with the subject barefoot. Each experiment consisted in observations with the subject in the recumbent and erect postures and during locomotion. In the supine position each subject moved his foot and ankle through their range of movement; performed isometric contractions against resistance in dorsiflexion, plantar flexion, inversion, and eversion; and carried out circumduction of the foot. In the erect posture, observations were made during the following procedures: rising from a seated position to a relaxed standing position, first on a level surface and then on an inclined (uphill) and on a declined (downhill) plane of 20 degrees each; shifting the weight onto one extremity, pausing, and then onto the other; shifting the weight onto the front part of the feet without raising the heels and then back to the heels; changing from a relaxed standing position to one with the knees hyperextended; rising onto the toes from an erect standing posture and sustaining this position for about fifteen seconds; balancing on one extremity with the contralateral hip and knee flexed to 45 or 90 degrees; and standing on one foot and rising to the tiptoe position. Observa-

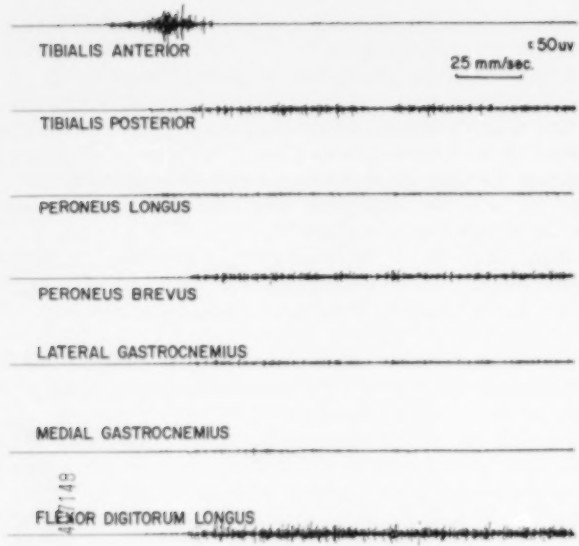

FIG. 2-A

Figs. 2-A, 2-B, and 2-C: Electromyograms of different subjects during relaxed standing. Electrical silence was established in the seated position. Strong contraction in the tibialis anterior and extensor digitorum longus was evoked as the subject rose to his feet (see text for symbols of leg muscles).

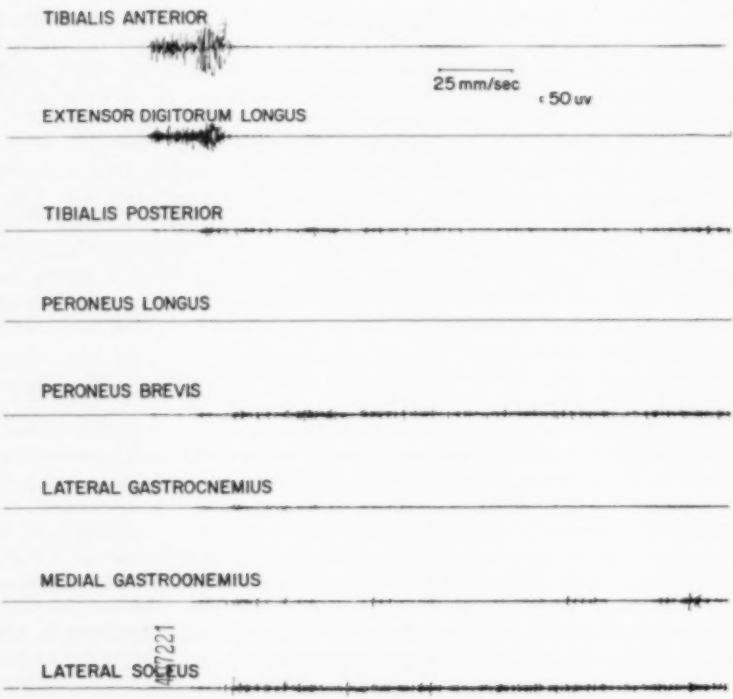

FIG. 2-B

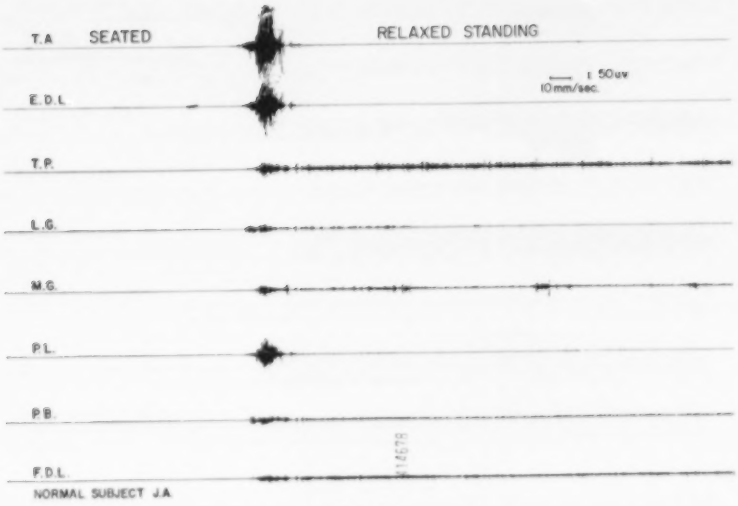

FIG. 2-C

tions were made also during walking and stair-climbing. Each procedure was repeated three or more times.

The subjects were indoctrinated prior to each experiment. They were told that changing the position of the head, trunk, or upper extremities would cause changes in tension in the leg muscles and thus change the records. They were instructed to move only on command and to perform the requested activity as they would normally do it. The techniques of the experiment were planned to keep operational instructions to a minimum.

To record the stance and swing phases of walking, a runway, 120 inches in length, was constructed of two parallel units, one to be in contact with each foot. These units were composed of two strips of galvanized-iron sheeting, six inches wide and ninety-six inches long, which were attached to two plywood boards ten inches wide and ninety-six inches long. Wooden slats one-quarter of an inch thick were nailed lengthwise to the boards on each side of the metal sheeting. Chicken wire was attached to these slats and stretched tautly over each unit. A plastic mat was placed over both units. Electrical wiring was attached to the chicken wire and iron sheeting on each unit and was connected in series to a three-volt dry-cell battery. An electromagnetic signal was suspended above one channel of the ink-writing dynograph. Contact between the wire and iron sheeting caused by contact of the subject's foot closed the circuit and deflected the pen on the moving electromyogram, thus delimiting the stance and swing phases of the extremity under study. The design of this runway separated the feet by approximately two inches and permitted the recording of four successive steps.

Electrodiagnosis or palpation, or both, during manual muscle testing by an experienced physical therapist were used to locate the muscles under study. The surface electrodes were monel-metal disks, 0.8 centimeter in diameter, with a hollow depression. They were placed equidistant from the motor point or over the belly of the muscle with a minimum interelectrode space of two centimeters and on a line parallel with the muscle fibers. A mild erythema was produced by rubbing the skin of the selected areas with electrocardiographic jelly. The disks were filled with this substance and sealed in place with aeroplast and adhesive tape. Because of the close anatomical proximity of the muscles, circumduction was performed by the subject to establish the fact that the action currents of individual muscles were being recorded (Fig. 1). Thus, the timing and magnitude

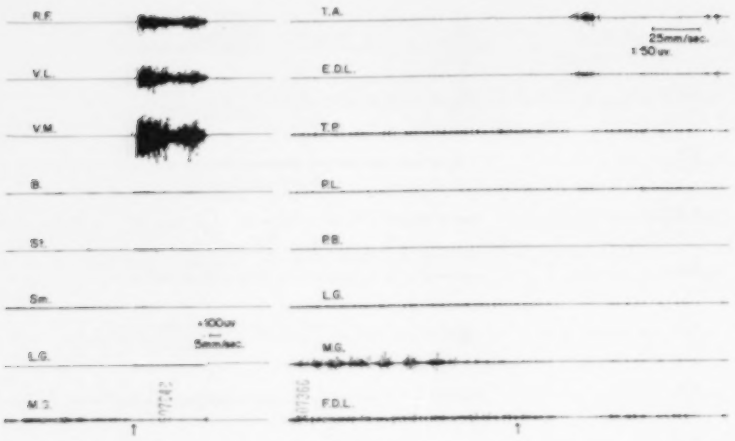

FIG. 3

Electromyograms of two subjects whose recordings were obtained in two different studies. Arrows indicate volitional hyperextension of the knees during relaxed standing (R.F. = rectus femoris; V.L. = vastus lateralis; V.M. = vastus medialis; B = biceps; St. = semitendinosus; and Sm. = semimembranosus).

of action potentials were believed to differentiate one muscle from another.

In toto, thirteen experiments giving data from 816 electromyograms were subjected to analysis. The patterns of muscle action of the different subjects under the various conditions prescribed were superimposed and compared by use of a view box. The records of those subjects who repeated the same experiment several months later were also compared, and the electromyograms of the two studies were found to duplicate each other.

INTERPRETATION OF RESULTS

Typical recordings of the action potentials of the leg muscles during relaxed standing are illustrated in Figure 2. At first, electrical silence in all muscles was established during relaxed sitting, the subject then rose to his feet, which was designated on the electromyogram by the activity in the tibialis anterior and extensor digitorum longus, and maintained an erect position for varying lengths of time. Bursts of action potentials elicited during the act of standing were limited

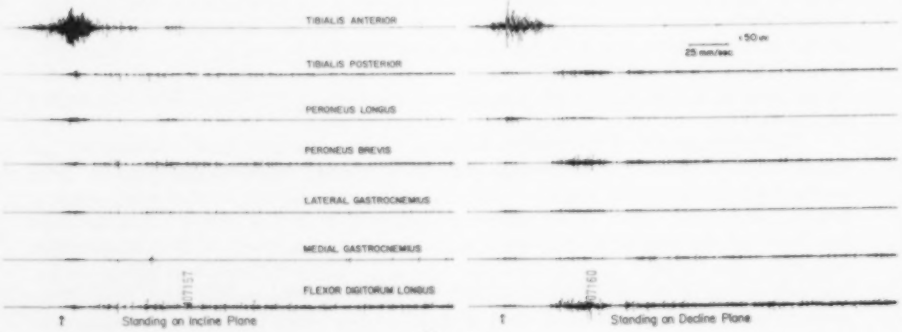

FIG. 4

Arrows mark the point at which the subject stood up from a seated position. These electromyograms may be compared with Fig. 2-A which is a record of the same subject standing on a level surface.

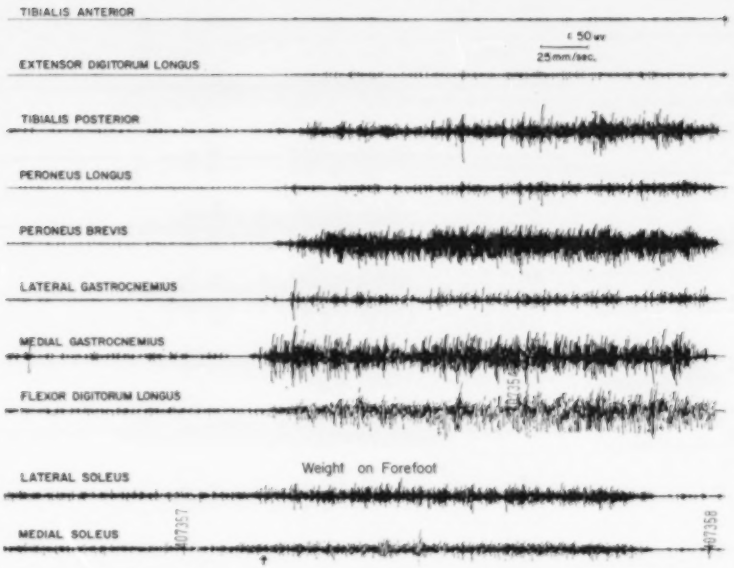

FIG. 5

Two records combined to show the action potentials elicited when the subject shifted the body weight from relaxed standing to a position with the weight on the balls of the feet.

primarily to the dorsiflexors; occasionally, a short period of increased activity occurred in the peroneus longus but this was not consistent among subjects or in any one person. The tibialis anterior and extensors to the toes acting from the foot planted firmly on the ground support the tibia on the tarsus as the subject rises to a standing position. Although periodic bursts of activity were usually present in the medial gastrocnemius during standing, activity in the lateral head was barely discernible in the majority of records. In the majority of electromyograms, continuous action potentials were observed from the soleus, tibialis posterior, peroneus brevis, and flexor digitorum longus during standing. The magnitude of electrical activity in these muscles varied with each subject but was consistent in the same subject as shown by comparison of each subject's records. Occasionally, minimum activity was observed in the peroneus longus, but this usually diminished during the period of standing prior to and following an activity. For example, this activity diminished before the subject shifted his weight onto the fore part of the foot, when his mind was occupied by thoughts of performing the act.

To determine whether the action potentials evoked from the medial head of the gastrocnemius were concerned with activity at the knee or ankle, the subject was asked to hyperextend the knees (Fig. 3), which resulted in cessation of activity in the gastrocnemius. Because changing of the position of the knee from a relaxed to a rigid joint by action of the quadriceps eliminates the electrical activity in the gastrocnemius, it seems reasonable to assume that the gastrocnemius is concerned primarily with alterations in knee position rather than with ankle function.

In the soleus, tibialis posterior, flexor digitorum longus, and, usually, the peroneus brevis, activity ceased during the change from the relaxed to the hyperextended position of the knee but activity in these muscles resumed after the subject was stabilized in the new posture. Because of the multiple insertions of the

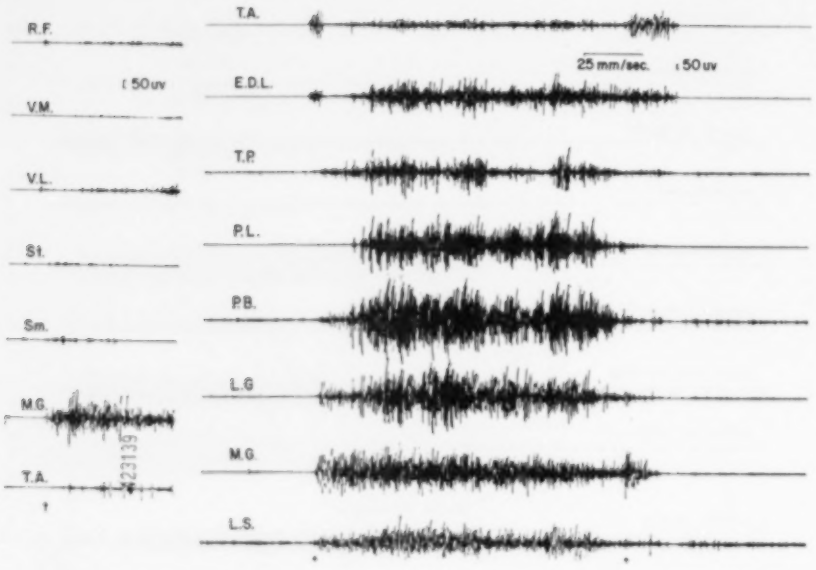

FIG. 6

Electromyographic recordings of two subjects. Electrical activity was evoked in the thigh and leg muscles as the subject rose onto the toes of both feet. The arrow on the right designates the return to relaxed standing (the symbols for the thigh muscles are the same as in Fig. 3).

toe flexors and the many joints which their tendons cross, we are uncertain whether the function of this muscle during standing is concerned with the position of the tibia on the talus or with the position of the tarsal joints. Further investigation is necessary to clarify this point. In any event, it seems evident that during relaxed standing the anteroposterior movements of the tibia on the talus are regulated by the three penniform muscles—the soleus, tibialis posterior, and peroneus brevis—which are already under tension by virtue of the change in position of the foot from the relaxed free position of about 30 degrees of plantar flexion to a right-angle position of weight-bearing. The soleus acts by a direct pull on the calcaneus. The tibialis posterior and peroneus brevis act by virtue of their pulley system around the posterior aspects of the medial and lateral malleoli at the ankle and have a two-to-one mechanical advantage over the soleus in regulating the anteroposterior movements of the tibia on the talus. The attachment of the tendon of the tibialis posterior on the plantar surface of the foot is such that this muscle is in an excellent position to act rapidly in response to proprioceptive stimuli caused by changes in tension in the tendons and ligaments as the center of gravity of the body moves forward, depressing the longitudinal arch. The tibialis posterior and peroneus brevis on each foot appear well placed to modulate the very minor transverse sway. Since the body weight is carried on the lateral borders of the feet, as well as on the heels and front part of the feet, it is conceivable that transverse sway during stance with the weight equally distributed on the two feet is controlled solely by the peroneus brevis on each side.

Relaxed standing with the feet on an inclined or on a declined plane of 20 degrees (Fig. 4) does not influence the magnitude of the action potentials in the contracting muscles or change the muscles which participate, as shown by comparison of Figure 4 with Figure 2-A. In comparing the records of all subjects the extent of contraction in the soleus is comparable to that seen in the flexors of the toes. When a person is standing on an inclined plane, the knees are prone to slight hyperextension, and the body weight is shifted forward to adjust the center of

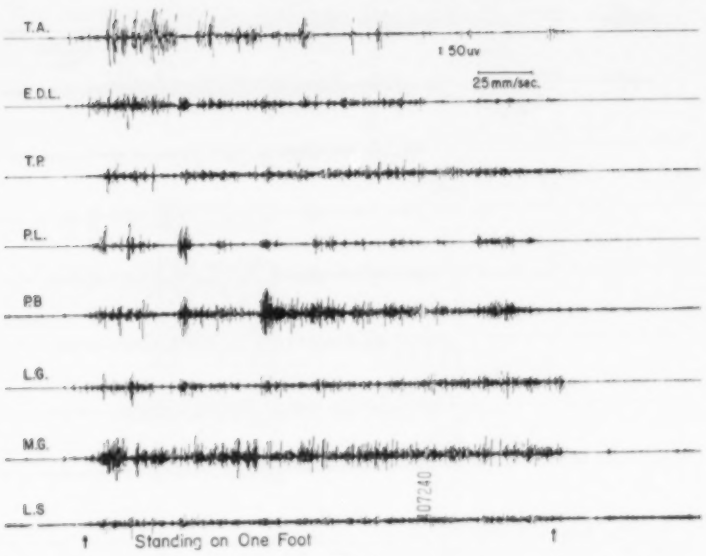

FIG. 7

Action potentials elicited in the weight-bearing extremity. The non-weight-bearing extremity was flexed 45 degrees at the hip and the knee.

gravity within the supporting base. The segmental alignment is reversed when compensating for standing on a declined plane. These findings are contrary to those presented by O'Connell. He demonstrated that the dorsiflexors were more active when a person was standing on an inclined plane and that the plantar flexors contracted more strongly during standing on a declined plane. Possibly, his subjects were making a conscious effort to maintain the same posture on each slanted plane as when they were standing on a level surface.

When the subject shifted his body weight forward so that the mechanical axis fell in front of the geometrical center of the supporting base (Fig. 5), strong activity was demonstrated in the medial gastrocnemius, peroneus brevis, tibialis posterior, flexor digitorum longus, and soleus. Comparison of the action potentials of the two heads of the gastrocnemius shows that the lateral head contributes relatively little to this activity.

If the body weight continues forward, the heels lose contact with the floor, and, by strong contraction of the plantar flexors with a quick check in the forward movement of the trunk, the subject attains a new stable position on the balls of the feet (Fig. 6). As seen in this record, the initiation of action potentials in these muscles varies in timing. The medial gastrocnemius contracts strongly as the weight shifts forward. This was also seen in the previous illustration. Simultaneously, activity usually begins building up in the tibialis posterior, peroneus brevis, and soleus and reaches a peak before maximum contraction occurs in the peroneus longus and lateral gastrocnemius. Since, as illustrated, the hamstrings and quadriceps contribute very little to this activity, and because it is extremely difficult for the subject to rise on his toes with locked knees, it may be assumed that the gastrocnemius plays a major role in adjusting the relationship of the femur on the tibia, whereas the plantar flexors act to control the position of the tibia on the foot. Once the position is assumed, the action potentials in all muscles drop in magnitude to a level of muscular activity sufficient to maintain balance on the fore part of the foot.

Shifting the weight from both feet to one extremity evoked action potentials in all muscles sampled in the supporting extremity. The response was magnified

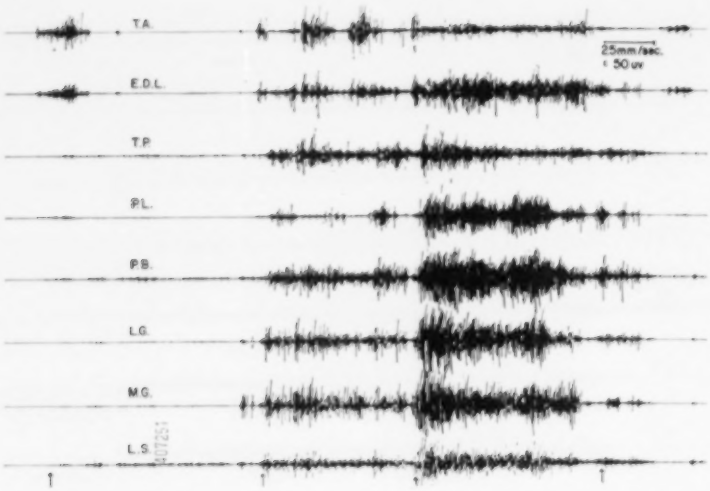

FIG. 8

Reading from left to right, the arrows delimit the action potentials recorded from the weight-bearing extremity during the following activities which were performed in continuity: relaxed standing, standing on one foot, and rising and standing on the fore part of one foot.

when the non-weight-bearing extremity was flexed at the hip and knee (Fig. 7). Bursts of muscle activity occurred as the subject endeavored to maintain his equilibrium. The magnitude of electrical activity varied from subject to subject,

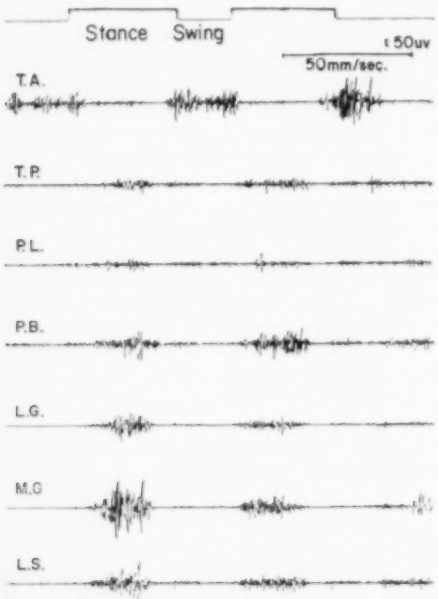

FIG. 9

Pattern of electrical activity during barefoot walking.

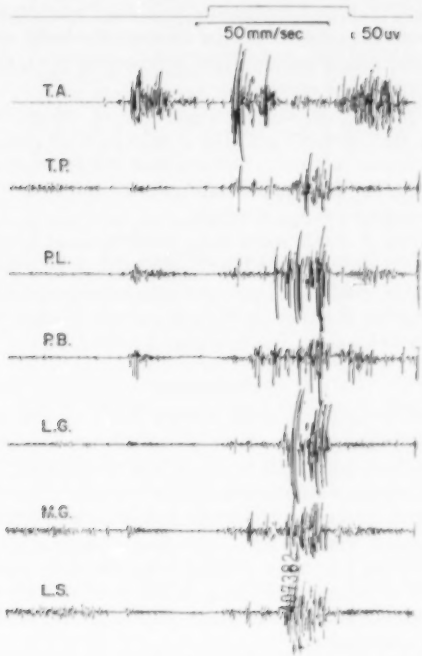

FIG. 10

A section of the pattern of action potentials of the right leg during stair-climbing. Deflection of the marker upward indicates the time that the right foot is in contact with the floor while the left foot is being placed on the first step. The marker drops as the right extremity is moved to the second step.

being less in the person most adept at standing on one foot. The more acute the angles of flexion of the non-weight-bearing extremity, the greater the contraction of the muscles in the supporting limb.

The action potentials evoked during the clinical test for a rating of so-called normal strength in the gastrocnemius are illustrated in Figure 8. The subject stands on one foot, flexing the contralateral extremity to 90 degrees at the hip and knee. Then, with minimum stabilizing assistance from the operator, the subject rises and balances himself on the ball of one foot. The effects of the various postures on the magnitude of the action potentials and on the participating muscles are obvious.

The patterns of activity of the gastrocnemius and soleus muscles during the stance phase of walking (Fig. 9) are not unlike those recorded during standing on one leg. Figures 7, 8, and 9 are electromyograms of the same subject recorded during one experiment and therefore can be used for comparison. In all subjects, the magnitudes of the action potentials evoked in these two muscles during walking were less than those elicited during the performance of rising on one limb or on both limbs onto the fore part of the foot. Furthermore, if the marker delimiting the stance and swing phases was set to record the position of the contralateral limb, the timing of the pattern of gastrocnemius and soleus activity coincided with the swing phase of the contralateral limb. Little can be added to the extensive analysis of human locomotion previously published except to reiterate the chain or linkage action of the lower extremity with respect to the function of these muscles. During the stance phase, the body moves forward, over, and past the

weight-bearing extremity. The hip extends to a near maximum, and at this point the heel is passively pulled away from the floor as the body weight continues forward. At this point the tibialis anterior and extensor to the toes contract to lift the fore part of the foot off the ground.

An additional comparison of the magnitude of triceps surae action during single-limb standing and push-off activity is seen in stair climbing (Fig. 10). The difference in extent of contraction is obvious and reinforces the concept that during walking these muscles function as stabilizers of the weight-bearing appendage while the other extremity swings through.

The data presented do little more than confirm what has been deduced clinically concerning muscle action in the lower extremity during weight-bearing. However, this experimental evidence may serve to clarify thinking concerning the function of these muscles. Further investigations are needed relative to the function of the muscles which act on the fore part of the foot.

SUMMARY

Multilead electromyographic studies were made on ten normal young adults to investigate the function of the muscles acting on the ankle during weight-bearing activities. Action potentials were picked up with surface electrodes from the tibialis anterior, extensor digitorum longus, tibialis posterior, peroneus longus and brevis, medial and lateral gastrocnemius, soleus, and flexor digitorum longus. The activities performed were: relaxed standing, standing on an inclined and on a declined plane, shifting the body weight from the fore part of the foot to the heel, standing on one extremity, standing on the toes of both feet and on the fore part of one foot, relaxed walking, and stair-climbing. The evidence presented supports the following conclusions:

In the erect posture the gastrocnemius acts on the knee to maintain a slight degree of flexion. The medial head is more active than the lateral.

The soleus, in conjunction with the tibialis posterior and peroneus brevis, adjusts the position of the tibia on the tarsus and secondarily contributes to the femorotibial relationship at the knee.

At the ankle the act of standing up is controlled primarily by strong contraction of the tibialis anterior and extensor digitorum longus. These muscles stabilize the tibia on the tarsus as a person rises to an erect posture.

The magnitude of the action potentials of the leg muscles is the same, whether the subject stands on a level surface or on a plane inclined or declined to 20 degrees. The postural alignment of the body is automatically adjusted to keep its center of gravity over the center of the supporting base.

In the gait pattern, the gastrocnemius and soleus muscles stabilize the knee and ankle during the stance phase while the non-weight-bearing extremity is in the swing phase.

Additional studies of the action of the intrinsic and extrinsic muscles of the foot with particular reference to their specific roles in weight-bearing activities are needed. These studies would provide the basic understanding needed to plan the most effective treatment and reconstruction procedure to be used when normal function has been impaired.

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Immunological Factors in Homogenous-Bone Transplantation

III. The Inability of Homogenous Rabbit Bone to Induce Circulating Antibodies in Rabbits *

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Most of the experimental work on reactions to homografts has been done with tissues other than bone. The current concept of the reaction to homografts is that the graft (skin, tumor, and so forth) releases antigen, which according to Scothorne, probably passes "directly via the host lymphatics in the graft bed" to the regional lymph nodes—the antibody-forming apparatus of the host. The antigen in homogenous tissue which calls forth the homograft reaction has not yet been identified precisely. A DNA-protein complex of cell nuclear origin was originally proposed, but more recent investigations have suggested that although DNA-protein may be necessary, the actual antigenic matter may be a lipopolysaccharide, separable from the DNA-protein [11]. There is also the undetermined role of the H2 system of antigens in tissue incompatibility [8].

The greatest body of evidence today supports the view that the agents which directly affect homografts are antibodies attached to intact whole cells, probably lymphocytes. Among the most convincing arguments in this regard are the elegant experiments by Algire and his associates, which showed that a homograft enclosed within a porous membrane will survive transplantation only if the pores of the membrane are small enough to prevent the passage of whole cells, but large enough to allow blood solutes (such as humoral antibodies) to enter freely. Several studies of bone homotransplantation have made mention of a cellular reaction around the graft [3,5,7]. Other authors [2,8], however, have described a role for circulating antibody as compared to the fixed tissue antibodies just mentioned. Gorer, in particular, emphasized the importance of the H2 antibodies found in response to the histocompatibility (H2) systems of antigens in mice. With the exception of a previous report by us [6], only one other attempt is known to have been made to identify circulating antibodies to homogenous bone. Bonfiglio, using a soluble fraction of rabbit bone injected along with an adjuvant into rabbits, reported the identification of a complement-fixing antibody of low titer.

The following experiments were undertaken to explore further the presence, if any, of circulating humoral antibodies in response to homogenous bone fractions used as antigen.

METHODS AND MATERIALS

I. *Circulating Antibody*

Under aseptic precautions, both femora and both iliac crests were removed from two New Zealand white rabbits (A and B). All epiphyseal and joint cartilage was removed. Twenty milliliters of serum was also removed

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from each of these rabbits by cardiac puncture and then stored frozen. The removed bone was wrapped in a sterile towel and broken up into smaller pieces with a hammer, the cancellous bone being further minced with scissors. These fragments of bone were then pulverized further in the Waring blendor in the cold room at 4 degrees centigrade with enough normal saline solution to make a 25 per cent homogenate. The homogenate was allowed to settle, the supernatant was centrifuged, and the resulting supernatant frozen and stored at minus 40 degrees centigrade as the soluble fraction. The residue was also frozen at minus 40 degrees centigrade, reduced to a still finer state with a mortar and pestle under liquid nitrogen, and stored as the insoluble fraction.

Twenty New Zealand white rabbits, five to six pounds in weight, which were not litter mates were divided into two series of ten each. A preliminary control bleeding ("C" bleeding) of thirty to forty milliliters was taken from each rabbit, and the serum frozen at minus 40 degrees centigrade.

The first series of ten rabbits was further divided into two groups of five. One group (AIT) received the insoluble fraction from rabbit A which was injected subcutaneously in the back as an emulsion composed of two milliliters of adjuvant *, two milliliters of normal saline solution, and ten milligrams of the insoluble fraction of bone prepared as described. The second group of rabbits (AST) received one milliliter of adjuvant together with one milliliter of the soluble fraction from rabbit A injected intramuscularly.

The second series of ten rabbits was also divided into two groups of five and each group received injections in exactly the same manner as the first group except that the soluble and insoluble bone fractions used were from rabbit B (BIT and BST).

Each rabbit was bled (first bleeding) from the heart three weeks after the injection, and twenty milliliters of the serum so obtained was frozen and stored. One week later, a booster dose (four milligrams of the insoluble fraction, dispersed in two milliliters of normal saline solution, injected subcutaneously; two milliliters of the soluble fraction, injected intraperitoneally) was given to the appropriate rabbits and the animals were bled again ("B" bleeding) four or five days later. The serum procured from this bleeding was also frozen and stored.

A. *Insoluble Fraction*

The control sera and the sera taken from the rabbits in the AIT and BIT series (ten rabbits) were dialyzed against 1.4 volumes of 3M ammonium sulphate at 0 to 5 degrees centigrade [16]. The gamma globulin obtained by this procedure was washed with cold 1.75M ammonium sulphate, and redissolved in distilled water. This process was repeated until the gamma globulin had been precipitated three times; it was then dialyzed against normal saline solution. Some of these samples were lyophilized, but most of them were stored frozen at minus 40 degrees centigrade. The gamma-globulin content of the preparation was determined by measuring the extinction coefficient, using the value for $E\frac{1\text{ cm}}{2800}$ equals 0.01 [10].

The antibody content of the sera from the rabbits receiving the insoluble fraction was measured in the following manner. Approximately ten milligrams of gamma globulin from each of the three bleedings (control, first, and "B" bleeding) from each rabbit in this series were iodinated simultaneously with I^{131} [15] and the unbound I^{131} dialized away from the radiolabeled gamma globulin. The radiolabeled gamma globulin was then added to ten milligrams of bone (from A rabbit for AIT group and from B rabbit for BIT group) in

*Adjuvant consisted of 1.5 milliliters of arlacel A and 8.5 milliliters of bayol F, and dry killed tubercle bacilli to the amount of two milligrams per milliliter.

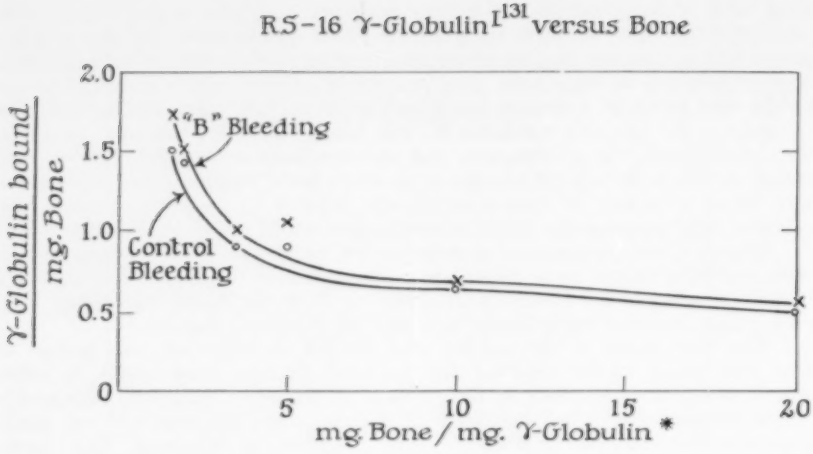

CHART I

γ-Globulin * represents radiolabeled gamma globulin.

saline solution containing 100 times the radiolabeled gamma-globulin weight of cold carrier protein (dialyzed concentrated human serum) to inhibit non-specific binding. This mixture was shaken in the cold overnight, and the supernatant removed after centrifugation. The residue of bone and radiolabeled gamma-globulin complex was washed in the same protein-rich saline, until the number of counts in the wash were constant and minimum. The remaining bone was then counted in a well-type scintillation counter and weighed. The radiolabeled gamma globulin retained was computed from its specific activity as earlier determined. The bound antibody was calculated by subtracting the radiolabeled gamma-globulin content of the control residues from the radiolabeled gamma-globulin content of the experimental residues.

A typical result of such an analysis is shown in Chart I where different proportions of bone to radiolabeled gamma globulin are plotted against the radiolabeled gamma globulin bound. It can be seen that while the data are nicely reproducible, it is necessary for accurate interpretation of results to be working in the straight line region of the curve, that is, where non-specific binding is constant and minimum. The vertical difference between the two curves, when significant, represents binding due to the presence of antibody. It can be seen by the curves in Chart I that there is no significant difference between the control and postinjection sera.

We feel, therefore, that values obtained at levels below seven milligrams of bone per milligram of radiolabeled gamma globulin are subject to a larger error than those obtained at this or greater values.

In Chart I there are two points shown at five milligrams of bone per milligram of radiolabeled gamma globulin which appear to represent a different population. These values were obtained from the same system, but were iodinated and assayed at a different time. This would appear to be due to a variable modification of the proteins due to the iodination, despite the fact that substantially less than an average of one iodine atom was introduced into each protein molecule (assuming the molecular weight of gamma globulin to be 160,000). From the reproducibility of the data within a given experiment, however, the method appears to be both highly sensitive and suitable for the quantitative demonstration of antibody to insoluble bone.

The data given in Table I show the results expressed as the ratio of

TABLE I

Rabbit	Bleeding	*Mg. Bone* / *Mg. GG** [1]	*μg Antibody GG* Bound* / *μg Control GG* Bound* [2]
Experiment no.			
15 I	C (control)	6.63	
	1 (first bleeding)	6.71	0.9
	B (booster)	6.62	0.8
15 II	C	6.67	
	1	6.62	0.7
	B	6.71	0.7
15 III	C	10.0	
	1	9.9	0.7
	B	10.1	0.7
16 I	C	5.0	
	1	4.9	1.3
	B	5.0	1.2
16 II	C	19.9	
	B	20.2	1.1
	C	10.0	
	B	10.0	1.1
	C	3.5	
	B	3.5	1.2
	C	2.0	
	B	2.0	1.1
	C	1.6	
	B	1.6	1.1
17	C	4.9	
	1	4.9	0.9
	B	5.1	1.0
18 I	C	8.3	
	1	8.3	1.0
	B	8.3	1.0
18 II	C	5.0	
	1	5.0	1.2
	B	5.0	1.4
19	C	11.7	
	1	11.6	1.1
	B	11.7	1.2
20 II	C	3.4	
	1	3.4	1.0
	B	3.3	1.4
21 II	C	1.7	
	1	1.6	1.0
	B	1.7	1.3
22	C	5.0	
	1	5.0	0.8
	B	5.0	2.4
23 I	C	5.0	
	1	5.0	0.8
	B	5.0	0.9
23 II	C	3.3	
	1	3.3	1.1
	B	3.3	1.1
23 III	C	1.7	
	1	1.7	0.8
	C	5.0	
	1	5.2	1.2
	C	8.4	
	1	8.7	1.0
	C	13.4	
	1	13.9	1.0

[1] GG* represents radiolabeled gamma globulin.
[2] Values close to 1.0 indicate a lack of specific binding, that is, binding similar to that of the controls.

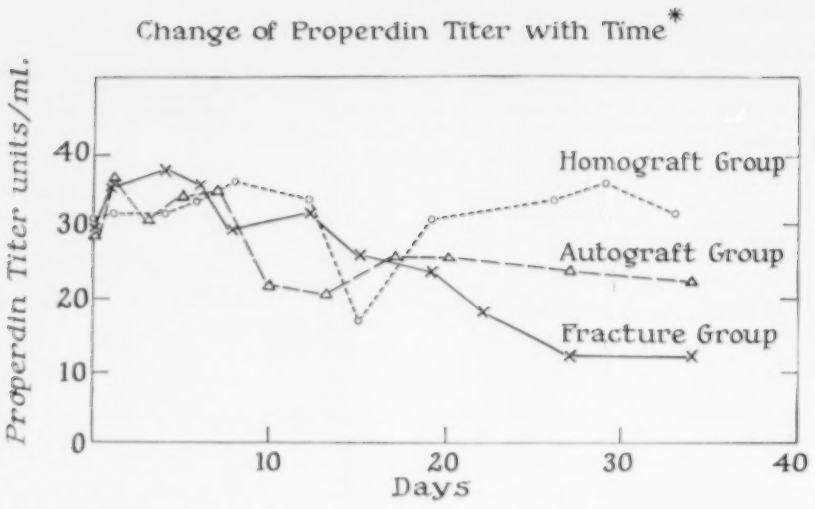

CHART II

*Each animal in a given group was bled on a given day. The titers shown are the averages of individual titers. Each point represents the mean titer of all sera in the given group.

"immune" radiolabeled gamma globulin bound to the control radiolabeled gamma globulin bound, after suitable washing and counting. The antibody levels of the "immunized" rabbits are on the same order as the control levels, and no evidence for a circulating antibody was found.

B. *Soluble Fraction*

1. *Hemagglutination:* The sensitive hemagglutination method of Boyden, as modified by Stavitsky, was used. No evidence of hemagglutination by the serum of any of the rabbits receiving the soluble fraction of the homogenous bone was observed.

2. *Agar diffusion technique:* Sera from the rabbits injected with the soluble fraction were also examined for precipitins by the double-diffusion method on agar-gel plates, essentially according to the method of Ouchterlony. All sera tested consistently failed to show the presence of antibody by this method.

II. *Properdin*

The reports of Pillemer and his coworkers concerning the properdin system suggested study of the possible relationship of this natural defense mechanism to the immune response in bone homografting. To investigate this, the following experiment was done (Chart II).

Three groups, each consisting of twelve healthy, young adult, New Zealand white rabbits were used. In Group I, closed manual fracture of the left tibia was done without external fixation. In Group II, the crest of one ilium was removed as an autogenous-bone graft and buried in the paraspinal muscles. In Group III, the iliac crests were exchanged between six pairs of rabbits (twelve rabbits in all) and buried in the paraspinal muscles. Serum samples on each rabbit were obtained on the day before operation and at approximately regular intervals for ten subsequent samples, until the animal was sacrificed five weeks postoperatively. The serum samples thus obtained were assayed for properdin titer at Dr. Pillemer's laboratory.

The properdin titer was found not to be affected by either autogenous or homogenous bone grafts, but the fracture group showed a gradual and sig-

nificant decrease in properdin titer. We believe that this might be due to release of cell-bound lipopolysaccharide in the adjacent traumatized area.

DISCUSSION

The statement has been made by Medawar [12] that "there is no known way of killing cells which does not greatly reduce their antigenic potency". The one feature that all methods of sterilizing, preparing, or storing homogenous bone have in common is the almost certain death of the contained cellular elements of the bone. If the source of antigen is in the contained cellular elements, one might expect that a homograft with this antigenic source removed (as by denaturation of the cell contents) would be essentially inert and accepted by the host as regularly as an autograft. This does not happen. However, it is not appropriate to make too exact comparisons between bone as a graft tissue and other tissues, such as skin or kidney. In the case of the latter tissues, the host is expected to accept living tissue, nourishing and maintaining it without replacement. With bone grafts, however, incorporation and replacement of the graft by the host is welcomed, and the quicker the surrounding tissue can be induced to form new bone, the better.

In the rabbit experiments reported here, three sensitive methods for the detection of circulating antibody failed to disclose evidence of an antibody in response to homogenous-bone fractions. The method of immunization used in these experiments has been employed successfully by others [9,19,20] in the production of antibodies to homogenous organs and is the most effective procedure available in this regard. It is highly possible, of course, that antigen was destroyed in the preparation of the immunizing material. Also, a noncirculating type of immunity of the delayed inflammatory type has not been excluded by these experiments. An immune reaction of this type may still be a possible mechanism for the homograft reaction. As just mentioned, cellular response to homogenous-bone transplantation has been documented by several workers. The role of this response in the fate of the bone graft, however, is still obscure.

SUMMARY

Groups of rabbits were injected with soluble and insoluble portions of rabbit bone. No circulating antibody could be detected by binding of radioiodinated gamma globulin, erythrocyte hemagglutination, or agar-gel diffusion.

Insignificant differences in properdin titer were observed in rabbit sera following experimentally produced fractures, autografts, and homografts.

NOTE: The authors wish to acknowledge the invaluable advice and assistance of the late Dr. Louis Pillemer in connection with the properdin studies. Grateful acknowledgment is also made of the technical assistance of Mr. Stanley Baer and Mr. Otis Ray.

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Medullary Fixation of Fractures of the Forearm

A Study of the Medullary Canal of the Radius and a Report of Fifty Fractures of the Radius Treated with a Prebent Triangular Nail *

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Medullary fixation of diaphyseal fractures of the radius has in the past yielded equivocal results. The unsatisfactory results were usually due to failure of the fixation device to immobilize bone fragments adequately to ensure union. A method of medullary fixation has been developed which seems to have some advantages over those methods previously reported.

HISTORY

Medullary fixation of diaphyseal fractures has been used for more than fifty years. Nicolaysen, according to Watson-Jones and others, first described the details of the principles of medullary fixation in 1897, and then Delbet described them [39] in 1906. Lambotte began axial fixation of fractures of the clavicle in 1907, and later used similar fixation in fractures of the distal radius and ulna [30]. These earlier attempts were with small pins which did not fully engage the cortical boundaries of the canal. In 1916 and in 1918 Groves first used a large nail for two femoral fractures which fully engaged the cortex, but because of the difficulties which arose, in these instances, with tissue reaction to metal, his efforts were not widely acclaimed, and Hoglund, in 1917, advocated the use of bone in medullary transplants, inlays, and pegs, and advised against the use of any metal.

After the work of Venable, Stuck, and Beach in 1936 on electrolysis of metal *in vivo*, one great disadvantage of medullary fixation was overcome, and during the last twenty years medullary fixation has come of age. In 1937 and 1939, L. V. Rush and H. L. Rush reported use of a Steinmann pin in the medullary canal of the ulna in a comminuted Monteggia fracture, and in the medullary canal of the femur for a subtrochanteric fracture. In the subsequent years, after much study, they developed pins and techniques which they advocated for numerous fractures of the extremities [25]. In 1937 Murray began the use of axial wire fixation for fractures of the clavicle; in 1940 he reported twenty-nine cases so treated without infection or non-union and proposed the use of this method in bones with small medullary canals such as the radius, ulna, and fibula. Concurrently, Lambrinudi, in 1939, used Kirschner-wire fixation in two cases of non-union of the radius and ulna.

In March 1940, at the German Congress for Surgery, Küntscher presented convincing evidence concerning the value of a medullary-fixation device which snugly fitted the entire length of the bone [30]. This soon received wide acclaim in Germany, but, because of World War II and the resultant lack of exchange of foreign literature, his efforts received little publicity in this country at that time. After the war, the results of his work were reviewed here and for the most part were widely accepted. In this country over the past ten years Street [32,33,34,35] and Lottes have modified the materials and techniques for medullary fixation of the femur and tibia to the point where, under proper indications, this method has become the treatment of choice.

There are essentially two different principles of medullary fixation in use

* Read in part at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 27, 1959.

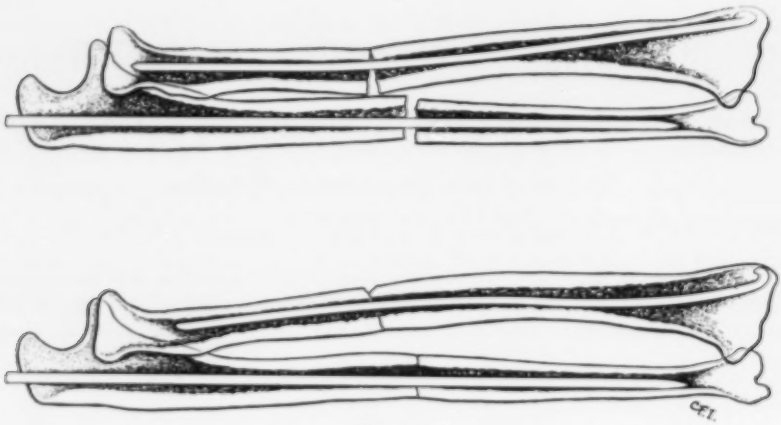


FIG. 1

Drawings demonstrating the effect of distraction of the ulna by loss of the radial bow. (From Smith, Hugh, and Sage, F. P.: Medullary Fixation of Forearm Fractures. J. Bone and Joint Surg., 39-A: 91-98, Jan. 1957.)

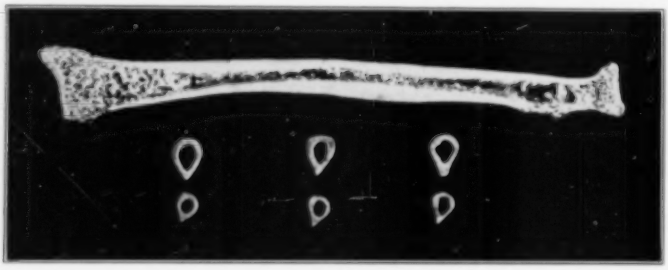


FIG. 2

The cross-sectional contour of the medullary canal of two radii at three points along the diaphysis.

today. The first is the three-point fixation described by Rush [24], in which the nail does not fill the medullary canal. In this situation fixation depends on the springiness of the metal which maintains contact between the device and the bony cortex at three points along the medullary canal. This means that a curved pin is placed down a straight canal, or a straight pin down a curved canal. The other principle is that of Küntscher in which firm contact of the nail against the cortical walls of the canal both above and below the fracture gives fixation [17]. Certainly, if the metal in this instance is sufficiently rigid, immobilization will occur.

The advantages of medullary fixation for fractures of the femur and tibia have not been apparent in fractures of the radius and ulna. At the Campbell Clinic, the results of medullary fixation of forearm fractures have been evaluated in three investigations. In 1949, Knight and Purvis reported comparative results in forty-one fractures of the radius and ulna treated by manipulation, thirteen fractures treated by open reduction without rigid internal fixation, twenty treated by plates, fifteen treated by primary bone-grafting, and eleven treated by medullary wires. In the last group of fractures there were six unsatisfactory results, due to loss of rotational alignment, angulation, or non-union. Bachynski and Smith, in 1953, reviewed seventy-nine patients with fractures in the diaphysis of the radius, the ulna, or both forearm bones, and found a high incidence of malalignment, malunion, or non-union; over 50 per cent had unsatisfactory results. In 1955, under the sponsorship of the Office of the Surgeon

General of the United States Army, the results of a series of 555 fractures of the forearm in 338 patients were analyzed at the Campbell Clinic [29]. These patients came from eighteen orthopaedic centers scattered throughout the United States and had been treated by men thoroughly experienced in the principles of medullary fixation. Kirschner wires, Küntscher V-nails, Steinmann pins, and Lottes forearm nails had been used, as well as Rush pins which were distributed for the project. In 416 fractures of the radius and ulna in which medullary fixation was used (188 in the radius and ulna, fifty in the radius alone, and seventy-nine in the ulna alone), non-union was found in 21 per cent. So high a rate of non-union could not be judged as favorable to medullary fixation. However, when those fractures with Kirschner-wire fixation, which had a non-union rate of 38 per cent, were excluded, a non-union rate of 14 per cent in fractures of both bones of the forearm and in fractures of the ulna alone was found. In fractures of the radius alone, however, the incidence of non-union remained at over 20 per cent.

To judge from the results reported elsewhere in this country, there appear to be three schools of thought on medullary fixation of the forearm, and all regard it as ideally a good procedure. One group [25,26,27,28] wholeheartedly endorsed it, but these proponents of the method presented only relatively small series of cases or no cases at all, so that valid conclusions cannot be drawn concerning their results. A second group [36] favored closed reduction where possible, using medullary fixation only where closed reduction is unsuccessful. The third group [1,5,15] favored closed reduction wherever possible and pin fixation of the ulna and plate or screw fixation of the radius when necessary.

Elsewhere in the world, the first enthusiasm for Küntscher medullary nailing in the forearm has waned. Böhler, first an advocate [2], later stated in 1949 [3] that he no longer used it for fractures of the tibia or of the forearm. Palmer, in 1950, stated: "Intramedullary nailing presents many problems and with it we have encountered greater technical difficulties than with any other method" [39]. In other centers in Europe, as in this country, medullary fixation of the forearm continues to be used, but most reports from all parts of the world have emphasized the difficulties encountered.

PRESENT PROBLEMS

In view of the failure of medullary fixation, the question as to whether open or closed reduction of fractures of the forearm should be used has remained unsettled. In the hands of most orthopaedic surgeons, closed reduction has been unsatisfactory since this method of treatment represents a compromise in which malposition is accepted to ensure union. However, for some surgeons, such as Evans and Patrick, these fractures have produced less of a challenge. Certainly, at present we would agree with those who believe that the preferred treatment for a closed fracture is to reduce the fragments anatomically by manipulation and to immobilize them satisfactorily with plaster. The fact that this often cannot be achieved, however, is attested by Compere, Stuck and Thompson, Howell, Kennedy, and Knight and Purvis. The use of plates and screws has likewise been advocated in lieu of medullary fixation—and with slotted plates the contact compression described by Eggers and his associates can take place—but in this situation there is also a high rate of non-union, because the insertion of a plate requires extensive dissection and periosteal stripping [5,10]. If a satisfactory method of medullary fixation could be devised, it might become the preferred treatment. Open reduction always brings the possibility of infection, but with aseptic technique there is little or no difference in the rate of infection after medullary nailing under closed and under open methods. The advantages of nailing by open reduction far outweigh those of nailing with closed reduction when all complications incident to the latter are considered.

The disadvantage of medullary fixation—the delaying of the formation of

callus—has appeared in the past to be more theoretical than real because clinical studies of fractures of the femur have suggested that after medullary fixation there is neither delay nor acceleration of healing. The recent work of Trueta and Cavadias, however, on the destruction of the nutrient artery of the bone during medullary fixation, with loss of endosteal and interstitial callus and overproduction of periosteal callus, is most convincing. This perhaps accounts for some of the earlier reports on the overproduction of callus both at and away from the fracture site. In the present study of the radius and ulna, as shall be discussed later, a delay in production of interstitial callus between the cortices was found.

The problem of fat embolism seems to be purely theoretical. Although manometric studies on the medullary cavity have shown that an increase of pressure develops during the driving of the nail [22,23], clinical studies have not substantiated an increase in the incidence of fat embolism with this method of treatment [34]. Certainly, open reduction of the fracture would tend to decrease these pressures.

The unsatisfactory results often encountered in medullary nailing of the forearm have been due primarily to either lack of fixation of the radius in anatomical position or failure to maintain that position. It has been strongly emphasized that in order to preserve pronation and supination, the normal arc [4] as well as the rotational alignment [19] of the diaphysis of the radius must be preserved. The fact that failure to maintain this arc also leads to the distraction of the fragments of a fracture of the ulna, with consequent malunion of the radius and non-union of the ulna, is not so well known [29] (Fig. 1). The ulna, being a relatively straight bone, is well suited for medullary fixation, and the rate of non-union after medullary fixation of solitary fractures of this bone is acceptable. This is not so, however, with the curved radius. Therefore, it seemed to me that a nail of appropriate shape and temper should be devised for the radius.

The Küntscher principle of filling the medullary canal seemed superior to three-point fixation. The medullary canal is elliptical or oval in cross section [2] (Fig. 2). A round pin, even with three-point fixation, may rotate in a round canal, and for this reason it was decided that the shape of the nail should be irregular in cross section: either triangular, square, rectangular, or of the contour of a parallelogram. The last two forms closely approach the contour of the canal, but nails with these shapes, which were small enough to be accommodated in the canal of the radius, were not sufficiently rigid to bending in the plane of their short diameters. A nail triangular in cross section was therefore planned.

If the Küntscher principle of filling the canal was to be followed, we realized that a straight nail could not meet all the necessary requirements. A prebent nail was therefore contemplated (Fig. 3), to be made of a metal sufficiently springy to bend as it traversed the canal from the point of insertion, but resilient enough to spring back to its prebent contour when finally seated, and, in the end, rigid enough to withstand the torsional, rotational, and angulatory forces of the muscles of the forearm.

To determine the proper curves and length of this nail, a thorough knowledge of the radial medullary canal in all its dimensions was necessary. Textbooks of anatomy lacked detail; the only material available was the study made by Ehman, as cited by Böhler [2], in which thirty radii were analyzed, and this was not sufficiently complete for individual analysis. The following study was therefore made.

STUDY OF RADII FROM CADAVERA

One hundred and twenty radii from dissected cadavera were obtained for study, over a period of eighteen months, from the Division of Anatomy of the University of Tennessee Medical Units. One hundred of these were retained for study of the medullary canal, and the remaining twenty were used in ex-

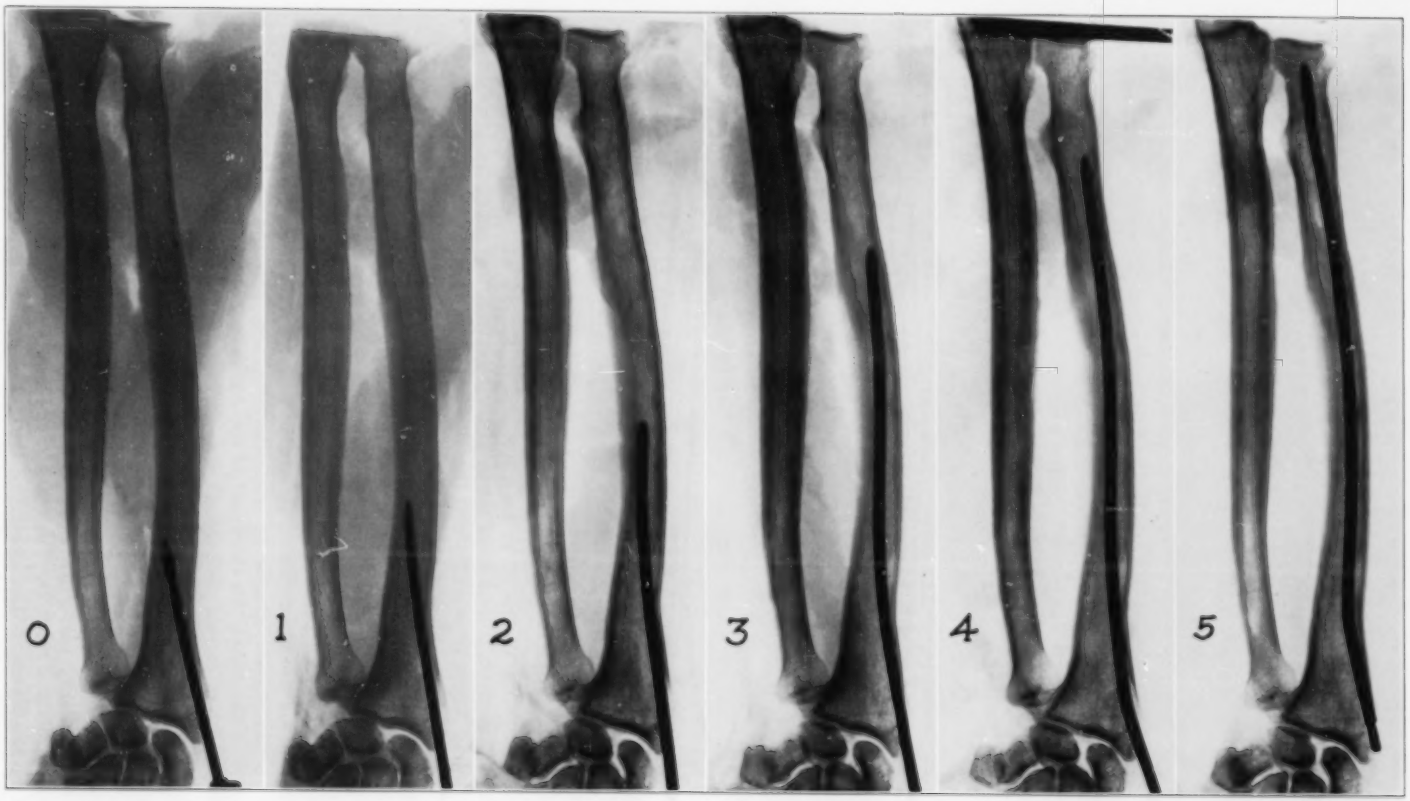


FIG. 3

A nail being driven up the radius of an amputated specimen. The nail must bend as it traverses the canal, and then finally spring back to its prebent shape. (Reprinted by permission from Stewart, M. J.: Medullary Fixation of Forearm Fractures. *In* American Academy of Orthopaedic Surgeons, Instructional Course Lectures, Vol. 15, 1958, p. 59. Ann Arbor, J. W. Edwards, 1958.)

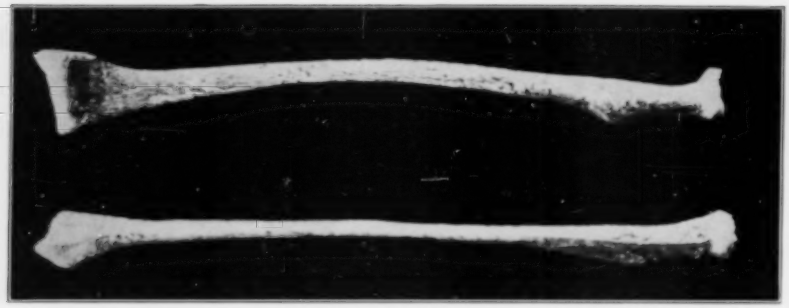


FIG. 4

Anteroposterior and medial-to-lateral views of an acrylic model of the medullary canal of a radius.

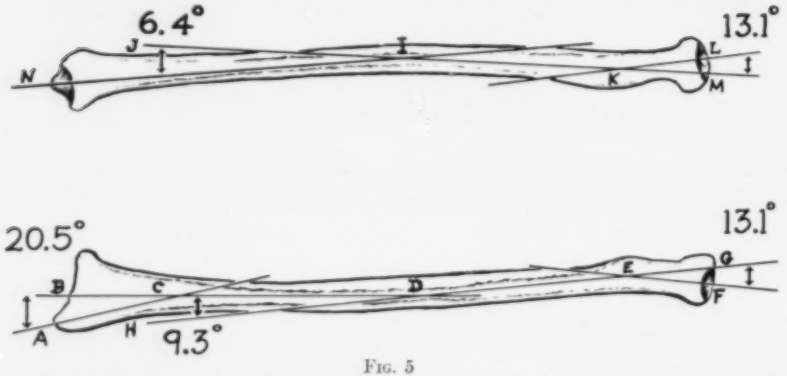


FIG. 5

Schematic drawings to show the two distal and two proximal angles in the longitudinal axis of the radial medullary canal and the distal angle of insertion of the nail.

perimental fixation of fractures, insertion and extraction of the nail, and other preliminary studies. The cause of death of the cadavera was generally associated with chronic illness or senility, and the average age was 66.3 years; three-fifths were male, and two-fifths were female. The ratio between whites and Negroes was one to two. From the age and the cause of death, one would expect that the medullary canal would be larger than that found in young, vigorous adults, and, consequently, that the inside measurements would be larger than those found in an average clinical series, but that the shape and contour of the canal, however, would be unchanged. The two bones of the forearm were cleaned of soft tissue, and the outside measurements of the radius were taken. The radius was then bisected in the anteroposterior or mediolateral plane, and the angulations and diameters of the canal, the thickness of the cortex in various parts of the shaft, and the extent of cancellous bone at each end were measured. For bisecting the bones, a bandsaw measuring 0.025 inch (0.635 millimeter) in thickness was used, which removed a width of bone measuring 0.75 millimeter. Accordingly, this 0.75 millimeter was added to the actual measurement of the anteroposterior diameter of the medullary canal if the bone was transected in the mediolateral plane and also added to the mediolateral diameter if the bone was transected in the anteroposterior plane. An attempt was made to divide the bone slightly off the central plane so that the thickness of the cortex at the four points measured would be unaffected by the amount of bone removed by the saw. Measurements were taken with inside and outside calipers.

The 100 radii consisted of forty-three pairs of radii, and nine single radii from the right side and five from the left. Their average length was 9.87 inches (25.06 centimeters), the right radius averaging 0.05 inch (1.27 millimeters) longer than the left. Of the forty-three paired radii, the right was longer in eighteen instances, the left was longer in nine instances, and the two sides were equal in sixteen instances. The shortest radius was 8.2 inches (20.8 centimeters) long; the longest was 11.4 inches (28.9 centimeters). The over-all width of the bone was measured at two points: the junction of the middle and distal thirds, and the junction of the middle and proximal thirds. At the junction of the middle and distal thirds, the average anteroposterior measurement was 11.6 millimeters, and at the junction of the middle and proximal thirds, 13.0 millimeters. The average medial-to-lateral width, at the junction of the middle and distal thirds, was 14.8 millimeters, and at the junction of the middle and proximal thirds, 16.4 millimeters. The nutrient artery was found to enter the volar aspect of the radius in a proximal direction at a point averaging 8.9 centimeters from the proximal end (range, 5.5 to 11.5 centimeters).

The radius and its matching ulna were then articulated, and the width of the interosseous space was measured in full supination at the junction of the middle and distal thirds of the radius and at the mid-point of the insertion of the pronator teres on the radius. At the former, the interosseous space ranged from 1.0 to 2.2 centimeters in width, and averaged 1.55 centimeters; at the point of insertion of the pronator teres the maximum width of the interosseous space was 1.8 centimeters and the minimum was 0.5 centimeter, with an average width of 1.08 centimeters. These widths are relative rather than actual, however, for during the cleaning process the articular cartilage was removed from the bones.

Several acrylic models were made of the medullary space of the radius after the bone had been sectioned and the medullary canal cleaned with a curette. From these models (Fig. 4) it was apparent that there are four curves in the medullary cavity of the radius which can be described in terms of four angles (Fig. 5): two distal (*BDG* and *NIM*) and two proximal (*DEF* and *IKL*).

The two distal angles (*BDG* and *NIM*) are formed by lines joining the geometrical center of the distal articular surface of the radius (*B,N*) with the center of the medullary canal at the level of the bicipital tubercle (*K,E*), with a common point of intersection at the center of the medullary canal at the level of the point of insertion of the pronator teres (*D,I*).

The two proximal angles (*DEF* and *IKL*), which open in the opposite direction from the distal ones, are formed by lines joining the geometrical center of the proximal articular surface of the radius (*F,L*) and the center of the medullary canal at the level of the insertion of the pronator teres (*D,I*), with a common point of intersection at the center of the medullary canal at the level of the bicipital tuberosity (*K,F*).

The proximal limbs of these proximal angles (*EF* and *KL*) were short, averaging 3.5 centimeters, whereas the distal limbs of the distal angles (*BD* and *NI*) averaged 13.2 centimeters. All four angles had a common segment, *DE* and *IK*, from the insertion of the pronator teres to the bicipital tubercle, which averaged 6.8 centimeters.

The complementary angles of those angles just described, two distal (*BDH* and *JIN*), and two proximal (*FEG* and *LKM*), were also determined. In the distal portion of the canal, angle *BDH* averaged 9.3 degrees, ranging from 6 to 13 degrees, and angle *JIN* averaged 6.4 degrees, with a range of from 3 to 10 degrees. In the proximal portion of the canal the complementary angles *FEG* and *LKM* were almost equal, ranging from 6 to 20 degrees, with average of 13.1 degrees. These two proximal angles are of no importance in medullary nailing, since their proximal limbs are so short that the nail, for reasons of safety, cannot extend far enough across the angles to obtain even three-point fixation.

TABLE I

AVERAGE THICKNESS OF CORTEX OF 100 RADII FROM CADAVERA

Aspect of Radius	Average Thickness at Junction of Middle Third and Distal Third (*Millimeters*)	Average Thickness at Mid-point (*Millimeters*)	Average Thickness at Junction of Middle Third and Proximal Third (*Millimeters*)
Posterior	2.6	3.2	3.0
Anterior	2.9	3.6	2.7
Lateral	2.6	3.1	2.8
Medial	3.7	5.9	5.0

TABLE II

SMALLEST ANTEROPOSTERIOR DIAMETERS AND THEIR LOCATIONS IN 100 RADII FROM CADAVERA

Diameter	Measurement (*Millimeters*)	Location	Percentage
Maximum smallest	8.25	Junction of middle third and distal third	32
Minimum smallest	3.0	Mid-point	48
Average	5.2	Junction of middle third and proximal third	10
		Mid-point and at junction of middle third and distal third	10

TABLE III

SMALLEST MEDIAL-TO-LATERAL DIAMETERS AND THEIR LOCATIONS IN 100 RADII FROM CADAVERA

Diameter	Measurements (*Millimeters*)	Location	Percentage
Maximum smallest	11.5	Junction of middle third and distal third	14
Minimum smallest	3.5	Mid-point	73
Average	6.9	Junction of middle third and proximal third	2
		Mid-point and at junction of middle third and distal third	11

Another angle (*ACB*), the angle of insertion for the nail, was also measured. This angle is formed by the intersection of line *BD*, which has already been described, and line *AC* which extends proximally from the intended point of insertion of the nail on the radial styloid (*A*) for a distance of two inches (5.1 centimeters) to the point of intersection (*C*). This angle ranged from 15 to 28 degrees (average 20.5 degrees). It represents the amount that the distal end of the nail would have to be prebent to permit its complete insertion into the medullary canal.

The over-all length between the mid-point of the subchondral bone of the head of the radius and a similar point beneath the distal articular surface averaged 23.4 centimeters. The cancellous bone in the radial metaphysis extended proximally from the radial styloid for an average distance of 5.12 centimeters, and distally from the head of the radius for an average of 3.7 centimeters. In almost every specimen, cancellous bone half filled the proximal medullary canal to a point just distal to the bicipital tubercle. The extent of cancellous bone in forearm fixation does not seem very important, however, because a nail small enough to be accommodated by the radius has so small a surface area that little if any fixation can be obtained in cancellous bone. This fact was borne out by

the clinical use of trial nails. The nail could always be rotated easily in the cancellous bone and did not become fixed until it was firmly seated against cortical bone.

The thickness of the anterior, posterior, medial, and lateral cortex of the radius was measured at three points: the junction of the middle and distal thirds, the mid-point, and the junction of the middle and proximal thirds of the radius (Table I). The diameter of the medullary canal in each plane (Table II and Table III) was usually inversely proportional to the thickness of the cortex at the point of measurement; that is, the thicker the cortex, the smaller the canal.

FIG. 6

Fractures of both the radius and the ulna treated by internal fixation with the earliest nails, three millimeters in diameter and of improper temper. Note the loss of the central bow of the nail. Nevertheless, solid union of both fractures was secured.

In 94 per cent of the cases, either the smallest anteroposterior diameter or the smallest medial-to-lateral diameter was located at the mid-point of the radius. In only 4 per cent of the cases were both the smallest anteroposterior and the smallest medial-to-lateral diameters found together at a point away from the mid-point of the radius. In these 4 per cent the smallest diameters were found at the junction of the middle and distal thirds. Therefore, at the time of open reduction of a radius, if the nail will fit the medullary canal in the region of the middle of the radius, it will nearly always be small enough to travel distally and proximally without becoming stuck.

The size of the medullary canal cannot be accurately measured roentgenographically alone, for three reasons. First, in the true lateral projection, the

ulna overlies the radius and in most instances obscures the cortical outline of the medullary canal of the radius. Second, it is impossible to estimate the amount of distortion in the roentgenogram owing to different sizes of the forearm and the resultant variations in the distance of the radius from the film. Third, as Ehman pointed out, the cortical outlines are not sharply outlined roentgenographically [2]. For these reasons, a trial fitting during the operative procedure before driving the nail is mandatory.

In an attempt to correlate some of these measurements, the anteroposterior diameters were plotted against the medial-to-lateral diameters at the three points on the shaft where they were measured. In almost every instance, as the anteroposterior diameter increased, so did the medial-to-lateral diameter, the latter almost always being larger.

There was no correlation between the smallest diameter at the mid-point of the radius and the over-all length of the bone, or between the degree of radial bowing and the over-all length, or between the degree of dorsal bowing and the over-all length, or between the width of the interosseous space and the over-all length. Neither was there any correlation between the anteroposterior diameter of the medullary canal at mid-point and the extent of cancellous bone in the distal end of the radius. This is probably due to the fact that only sixteen of the 100 specimens came from the age group below fifty; if a younger group had been measured there would probably be a correlation.

There was a slight correlation between the over-all length of the bone and the angle of insertion. This is to be expected because the longer the bone, the wider the distal end. With a wide distal end the line of insertion, *AC* (Fig. 5), would make a slightly less acute angle with line *BD*.

DESIGN OF THE NAIL

The reasons for choosing a nail triangular in cross section have been stated. From the foregoing study of 100 radii, we found that the distal angle in the nail (the angle of insertion) should be 20 degrees and the middle angle, corresponding to the radial bow, should be 170 degrees. From trial insertion and extraction of the nail, the appropriate proximal angle was found to be about 175 degrees. Since the point of insertion on the styloid lies about mid-way between the extreme anterior and posterior borders of the distal end of the radius, the distal dorsal arc of the radius could be disregarded.

The proximal end of the nail was rounded to form a skid, and the distal end was threaded for the attachment of the driving device.

The metal selected by Rush for his three-point-fixation nail seemed to fulfill the three requirements of springiness, resilience, and rigidity needed for this device. Accordingly, the first nails were cut down to a triangular cross section from larger round Rush nails. In the cutting process, however, the temper was evidently changed, and, after some difficulty, triangular samples were obtained of A.I.S.I. 316 stainless steel, of a Rockwell hardness of thirty on the C scale.

At the outset of the study, sample nails were made and inserted so that clinical trials could coincide with laboratory investigations. Initially, nails of the contour of an equilateral triangle measuring three millimeters on each side were used, but after the first two cases it was evident that this nail was not rigid enough, that it lost its radial bow during insertion, and that, although it immobilized the fracture, aiding union, it did not maintain anatomical reduction (Fig. 6). The size was therefore increased to four millimeters.

For the preliminary clinical study, the nails had a 15-degree angle of insertion, a 170-degree middle angle, and a 175-degree proximal angle. The angle of insertion was made two inches (5.1 centimeters) from the distal end, the proximal angle was one inch (2.5 centimeters) from the proximal end, and the mid-point of the longest curve in the nail was mid-way between the apexes of the other two. These angles turned out to be surprisingly close to the average angles

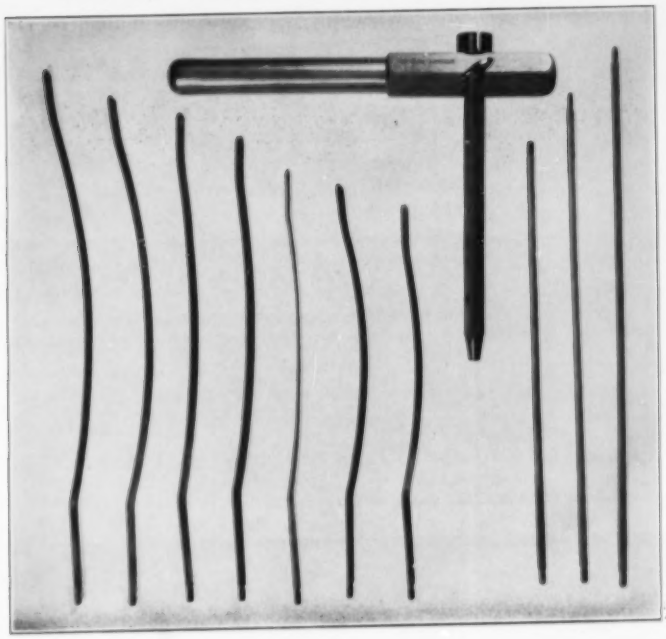


FIG. 7

The driver-extractor, and a full complement of nails for the radius and the ulna.

obtained in the cadaver study and have remained unchanged.

A straight four-millimeter triangular nail threaded on each end, to facilitate retrograde insertion, was also devised for use in the ulna, the theory being that a nail of triangular contour would give better stability than a round nail (Fig. 7).

CLINICAL TRIAL

By December 1, 1958, these nails had been used in more than sixty patients. As a preliminary report, an analysis follows of the first fifty patients in whom the nails were used in the radius alone or in the radius and the ulna in combination.

Case Material

In the fifty patients there were eighty-two fractures. Eighteen fractures in eighteen patients involved the radius alone, and sixty-four fractures in thirty-two patients involved both the radius and ulna. Prebent medullary nails were used to fix all the fractures of the radius. Straight medullary nails were used to fix the fractures of the ulna in twenty-nine patients. The remaining three were treated as follows: in one, the distal ulna was excised primarily; in the second, a fracture in the distal third was maintained by cast immobilization alone; and in the third, a comminuted fracture of the olecranon was maintained by a Knowles pin and a figure-eight wire loop. Thus, seventy-nine nailings were performed.

In Table IV the age distribution of the fifty patients is shown. This is a series of adults; no patient was under fifteen years of age. The locations of the eighty-two fractures are shown in Table V.

Of all the fractures in the radius, 70 per cent were either spiral, transverse, or oblique; the remaining 30 per cent were comminuted. In all fractures of the

TABLE IV

AGE DISTRIBUTION OF FIFTY PATIENTS

Age (*Years*)	No. of Patients	Percentage
15 to 20	6	12
21 to 40	21	42
41 to 60	18	36
Over 60	5	10

TABLE V

LOCATION OF EIGHTY-TWO FRACTURES

Bone Fractured	Location and No. of Fractures: Distal Third	Middle Third	Proximal Third	Total No. of Fractures
Radius alone	5 (27.7%)	13 (72.3%)	0	18
Radius (both bones)	4 (12.5%)	24 (75.0%)	4 (12.5%)	32
Ulna (both bones)	8 (25.0%)	21 (65.6%)	3 (9.4%)	32

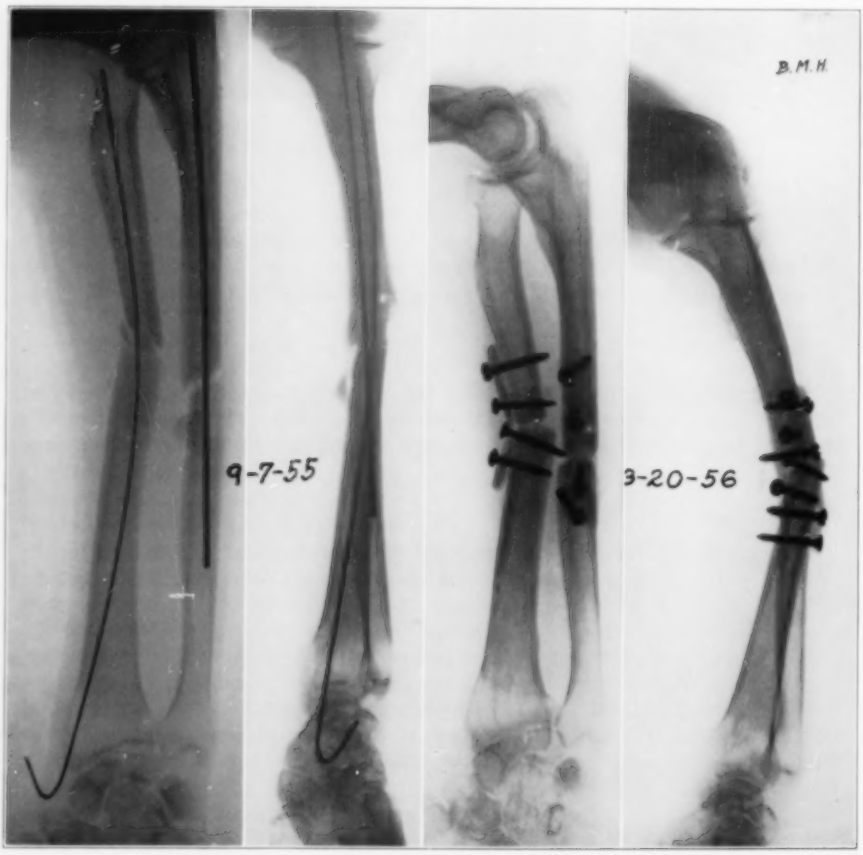


FIG. 8-A

Figs. 8-A and 8-B: Union was secured by medullary fixation eleven months after injury, after two previous procedures had failed.

ulna, approximately half were spiral, transverse, or oblique; one-eighth were segmental; and three-eighths were comminuted. In all instances, fractures involving the distal or proximal fifth of the bone were not subjected to medullary fixation. As in a previous series of patients in whom medullary fixation of the forearm had been performed [29], this series presented a rather formidable challenge: one-fifth of the patients had fractures or dislocations in the same extremity; one-fifth of the fractures were compound; one-eighth of the fractures had remained ununited for over six months prior to this procedure (Figs. 8-A and 8-B); approximately one-fifth had been subjected to nailing after a delay, for various reasons, of from fifteen to ninety days after injury; and in 16 per cent of the patients there was neurovascular damage in the same extremity prior to nailing. These preoperative complicating factors should be taken into consideration in appraising the end results reported here.

The postoperative follow-up of the patients in this series ranged from ninety days in two instances to well over three years in one instance; the approximate average follow-up was ten months.

Procedure

All the fractures of the radius were fixed with the prebent triangular medullary nail, and all the fractures of the ulna were fixed with the straight triangular medullary nail just described, with the exception of the three instances noted. Supplementary fixation of the radius with a wire loop or screw was used in seven of the fifty patients, and supplementary fixation with a wire loop was used in four of the ulnar fractures. This makes a rate of supplementary fixation of 14 per cent in both the radius and the ulna.

FIG. 8-B

FIG. 9

A solitary fracture of the radius in which no external immobilization was used. The fracture is now solid and the nail has been removed.

An opinion as to the degree of stability afforded by the fixation at the time of operation was recorded by the surgeon in all cases. In fractures involving the radius alone, stability was described as good or excellent in 94.5 per cent and as fair in 5.5 per cent (a single case). In fractures of both bones, the stability of the radius was termed either good or excellent in 91 per cent and fair in 9 per cent; the stability of the ulna was essentially the same.

The apposition of the major fragments of these fractures was graded on the basis of the opinions recorded by the operating surgeons at the time of surgery. No attempt was made to establish quantitative criteria. According to the surgeons' opinion apposition was excellent or good in all solitary fractures of the radius and good in both the radius and ulna in approximately 83 per cent of fractures of both bones. In the remaining cases it was fair, except for one fracture of the ulna where it was poor.

External fixation by a long arm cast was used in all cases, with the one exception of a solitary fracture of the radius (Fig. 9), for which no external support was used. Cast immobilization was maintained for six weeks or less in 16 per cent but it was continued in the remainder until roentgenographic evidence of solid union was seen. Nine per cent of the patients were immobilized for over six months. The mean period of cast immobilization for the entire series was twelve weeks.

Internal fixation was maintained until firm periosteal new bone was pres-

TABLE VI

DATA ON UNION IN EIGHTY-TWO FRACTURES

Bones Fractured	Union	Union Delayed for More than Six Months	Non-union	Total No. of Fractures
	No. of Fractures	No. of Fractures	No. of Fractures	
Radius alone	16 (88.8%)	1 (5.6%)	1 (5.6%)	18
Radius (both bones)	28 (87.5%)	2 (6.25%)	2 (6.25%)	32
Ulna (both bones)	28 (90.0%)	1 (3.3%)	2 (6.7%)	31*
Totals	72 (88.9%)	4 (4.9%)	5 (6.2%)	81

* In Tables VI, VII, and VIII is excluded one ulnar fracture treated by primary excision of the distal fragment.

ent. It was noted early in the series that although periosteal callus appeared fairly early, there was a definite delay in complete obliteration of the fracture line (Figs. 9 and 10). Even though the fracture was united by mature, bridging, periosteal new bone, it was often not until after the nail had been extracted that interstitial bone formed and completely obliterated the fracture. This coincides with the experimental findings of Trueta and Cavadias.

Grafts of chips of autogenous iliac bone were used to stimulate osteogenesis in one-sixth of the fractures involving the radius alone, and in one-third of the fractures of the radius and one-third of the fractures of the ulna where both bones had been fractured. These grafts were usually used in fractures for which nailing had been delayed because of various preoperative complications or for which nailing was performed in the treatment of a pre-existing non-union. These grafts were not used in fresh fractures treated primarily by intramedullary fixation.

Results

Union of the fracture is of paramount importance, and the results in this regard were gratifying (Table VI). In each of the three non-unions of the radius, the nailing had been complicated by penetration of the nail through the cortex of the proximal fragment (Figs. 11 and 12). The nail had not been extracted, but had been allowed to remain in this undesirable position. If it had been extracted and reinserted, we feel that there would have been a better chance for union.

In one of the patients in whom non-union of the ulna occurred, there had been pre-existing non-union for over one year; in the other, a large fragment of bone in a severely mangled elbow had been knocked loose and lost, so that adequate apposition was not obtained at operation.

Soft-tissue healing was not a problem in this group of patients. Two mild infections occurred—both in the radius—which responded readily to a few days of antibiotic therapy. In a third patient, who had a large open draining wound of the knee at the time of operation on the forearm, a delayed infection occurred approximately six weeks after medullary nailing (Fig. 13). It subsided after simple incision and drainage and the use of appropriate antibiotics; the nails were left *in situ*. Union occurred in approximately five months, and the nails were removed twelve months after insertion.

Although bridging callus formed readily in the radius and ulna (Table VII), there was a considerable delay in consolidation of the formed callus while the medullary nails remained *in situ* (Table VIII).

In appraising the range of motion obtained by the patients in this series, it should be kept in mind that there were a large number of complicating factors present before operation which would be expected to impair the functional result.

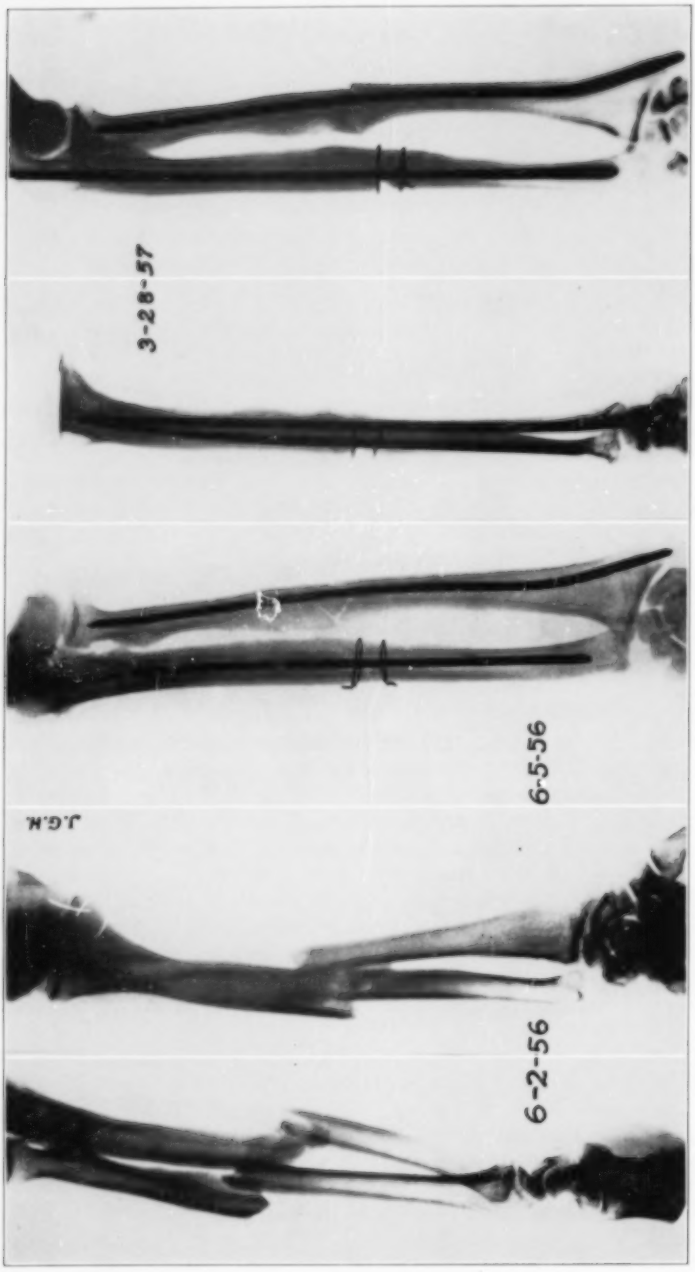


FIG. 10

Although fixation is firm, the fracture line is still partially visible in the radius; the indwelling nail retards interstitial callus. (Reprinted by permission from Stewart, M. J.: Medullary Fixation of Forearm Fractures. *In* American Academy of Orthopaedic Surgeons, Instructional Course Lectures, Vol. 15, 1958, p. 60. Ann Arbor, J. W. Edwards, 1959.)

TABLE VII

NUMBER OF WEEKS REQUIRED FOR APPEARANCE OF BRIDGING CALLUS

Bone Fractured	Appearance of Callus						
	Less than Nine Weeks	Nine to Twelve Weeks	Thirteen to Sixteen Weeks	Seventeen to Twenty-six Weeks	More than Twenty-six Weeks	No Appearance	Total No. of Fractures
	No. of Fractures	No. of Fractures	No. of Fractures	No. of Fractures	No. of Fractures	No. of Fractures	
Radius	13	2	0	2	1	0	18
Radius (both bones)	19	7	2	2	1	1	32
Ulna (both bones)	21	7	1	0	1	1	31
Totals	53	16	3	4	3	2	81

TABLE VIII

NUMBER OF WEEKS REQUIRED FOR CONSOLIDATION OF CALLUS

Bone Fractured	Consolidation						
	Less than Nine Weeks	Nine to Twelve Weeks	Thirteen to Sixteen Weeks	Seventeen to Twenty-six Weeks	More than Twenty-six Weeks	No Consolidation	Total No. of Fractures
	No. of Fractures	No. of Fractures	No. of Fractures	No. of Fractures	No. of Fractures	No. of Fractures	
Radius	1	5	4	5	2	1	18
Radius (both bones)	1	8	5	11	5	2	32
Ulna (both bones)	1	10	8	8	2	2	31
Totals	3	23	17	24	9	5	81

In addition, there were eleven patients who could not be evaluated in this regard. Of these, non-union resulted in five patients (three non-unions of the radius and two of the ulna) and each patient underwent a second operation to obtain union as soon as the non-union became apparent and before the arm had time to be as fully mobilized as possible. The other six patients failed to return for follow-up examination soon after the removal of the casts.

The criteria used to evaluate the range of motion were as follows:

1. *Slight limitation:* Elbow motion lacking less than 10 degrees of flexion and extension; pronation and supination each lacking less than 45 degrees; finger and wrist motion normal.

FIG. 11

Non-union occurred in this fracture. Note the wide medullary canal of the distal fragment and the penetration of the nail through the proximal cortex.

2. *Moderate limitation:* (a) Elbow motion lacking 10 to 20 degrees of flexion and extension; pronation and supination each lacking 45 to 90 degrees; finger and wrist motion normal; or (b) elbow, wrist, and finger motions normal; pronation and supination absent, but forearm in functional position.

In no case was severe limitation noted. In cases involving fractures of the radius alone, no limitation, or only slight limitation, occurred in 68.8 per cent, and moderate limitation occurred in 31.2 per cent. In forearms in which both bones had been broken, no limitation, or only slight limitation, was noted in 69.6 per cent; moderate limitation was noted in 30.4 per cent.

In three of the fractures of the radius in which both bones had been broken, there was slight loss of position (Fig. 14). This occurred in fractures of the distal third, and in fractures with comminution of the lateral cortex. It resulted in a

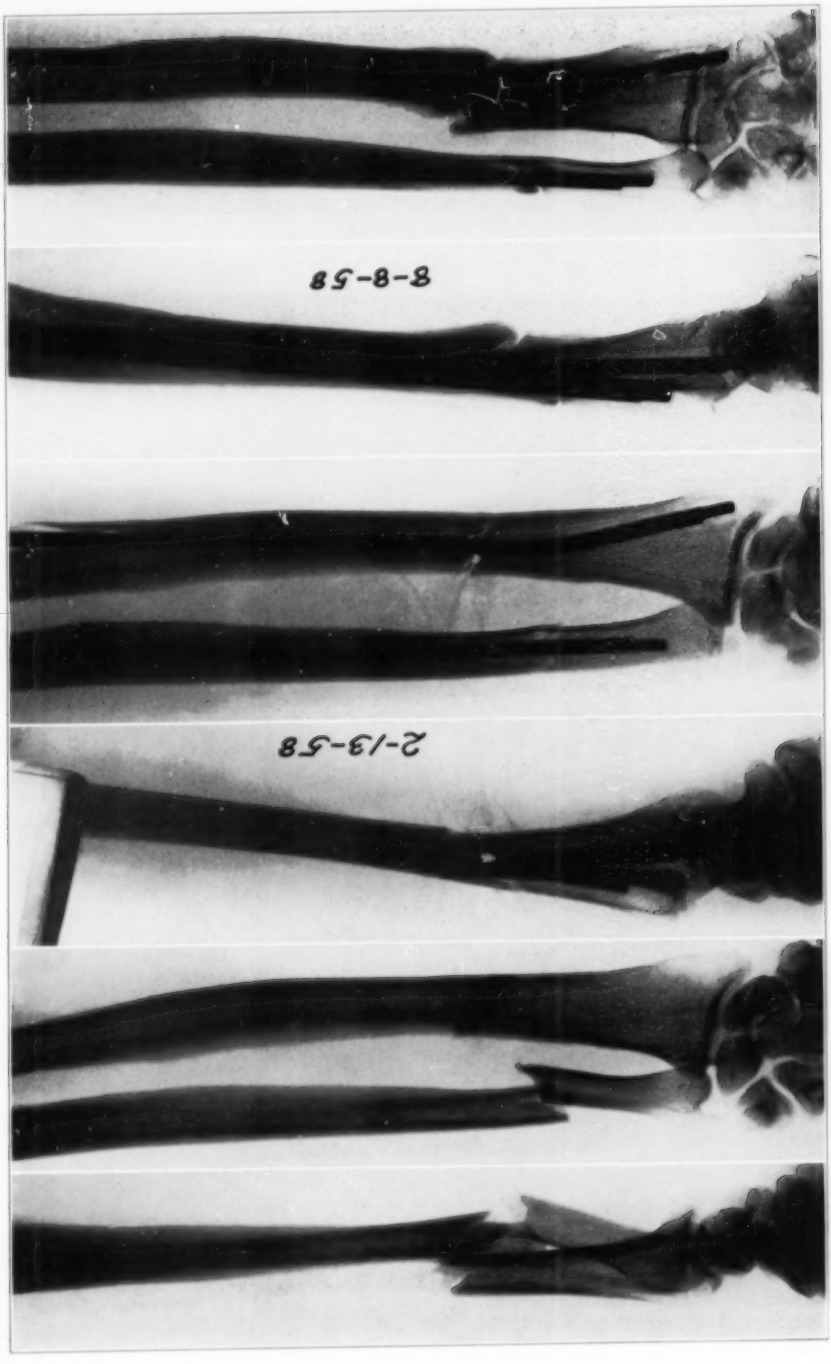


FIG. 12

Non-union of the radius in the distal third. Note the penetration of the nail through the proximal cortex.

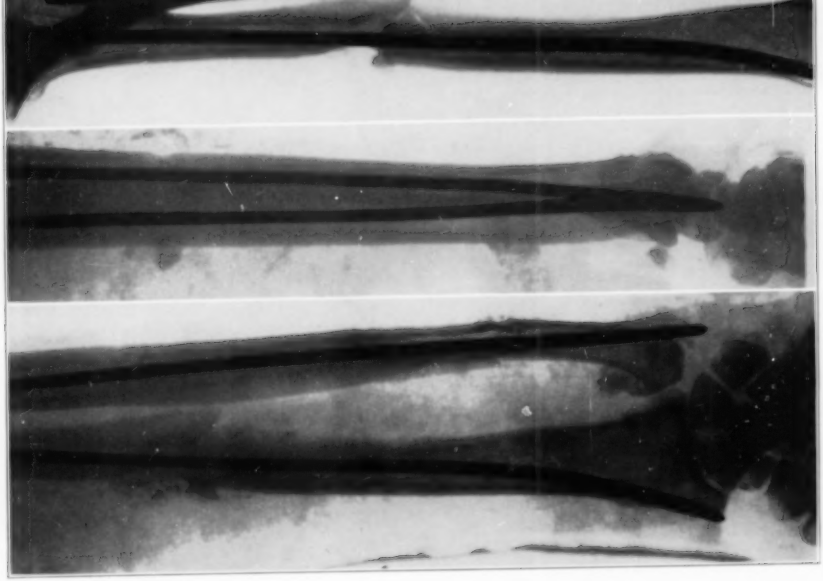
FIG. 13

g. It was thought to be metastatic from an open draining wound of the knee present at the
l by treatment, and union was secured approximately five months after nailing.

Fig. 14

...w in the nail occurred because of comminution of the radius.

Infection occurred in this radius six weeks after nailing. It was
time of nailing. Fortunately, the infection was controlled by treat



Loss of the radial bow in the

slight narrowing of interosseous space, and corresponding restriction of pronation and supination. In two patients with solitary fractures of the radius, shortening occurred and resulted in derangement of the distal radioulnar joint (Fig. 15). This complication occurred in fractures in the distal third or at the junction of the middle and distal thirds. In other patients, the nail was too long, and penetrated the wrist joint or carpal bones with resulting limitation of motion until the nail was extracted. After extraction, no significant limitation of wrist motion persisted in these cases. Minimum angulation occurred in one radius, with resulting loss of some interosseous space and limitation of motion. In three patients in whom the nail protruded through the cortex, non-union resulted (Figs. 11 and 12).

Complications

During the early clinical trial of the nail, several complications were encountered. Something was gained in knowledge as a result of each one, and a variation in technique was introduced to avoid repeating it. The most persistent difficulty was that encountered in driving the nail up a tight medullary canal. In four early cases, the nail protruded through the cortex, and in one case it split the distal shaft of the radius. The point of insertion was then moved from the radial styloid to the radial side of Lister's tubercle (Fig. 9). This point of insertion was then used in thirty-two fractures. Spontaneous rupture of the extensor pollicis longus tendon later occurred in three of these patients, despite the fact that the nail did not touch the tendon itself. Two of these cases were explored in order to perform tendon-grafting in one and tendon transfer in the other. In both cases it was found that the end of the nail was approximately one-fourth of an inch from the route of traverse of the extensor pollicis longus tendon. It was assumed that some tissue reaction had occurred in the tendon caused by the nail, with resulting gradual attrition and rupture of the tendon under minimum stress. The point of insertion was then changed back to the radial styloid, and was used in eighteen cases.

In the last six months, at the suggestion of duToit and Vesely, the radial nail has been rounded in cross section for the proximal 3.8 centimeters (Fig. 16); this modification has made insertion easier. Also, a reamer has been devised, the diameter of which is 0.78 millimeter less than the largest diameter of the nail. With this reamer both fragments may be reamed proximally and distally if the nail seems too tight. In two instances a butterfly fragment was knocked loose from the radius during nailing. We now take the precaution of examining the ends of all fragments carefully. If longitudinal cracks are seen, bone-holding clamps are placed in appropriate position on the ends of the bone during the process of reaming the canal and driving the nail.

Painful bursae occurred over the tip of the ulnar nail at the olecranon process in four instances and over the tip of the radial nail at the radial styloid in three instances. Synosteosis occurred between the radius and the ulna in one solitary fracture of the radius, and in one instance of fracture of both bones. During the process of insertion of the radial nail, the nail rotated 90 degrees in three instances (Fig. 17), and was allowed to remain in that position. This resulted in slight loss of interosseous space, but in none of these instances was there any significant loss of supination or pronation.

Secondary to open reduction of a fracture of the proximal third of the radius, one patient incurred partial damage to the radial nerve with loss of active thumb abduction. This, however, was a complication of the exposure; it was not because of the nail itself.

Ten per cent of the nails in the radius were extracted less than six months after operation, and 32 per cent were extracted more than six months after operation. Fifty-eight per cent remained *in situ* at the time that this study was completed (January 1959). In the ulna, 20.7 per cent were extracted in less than

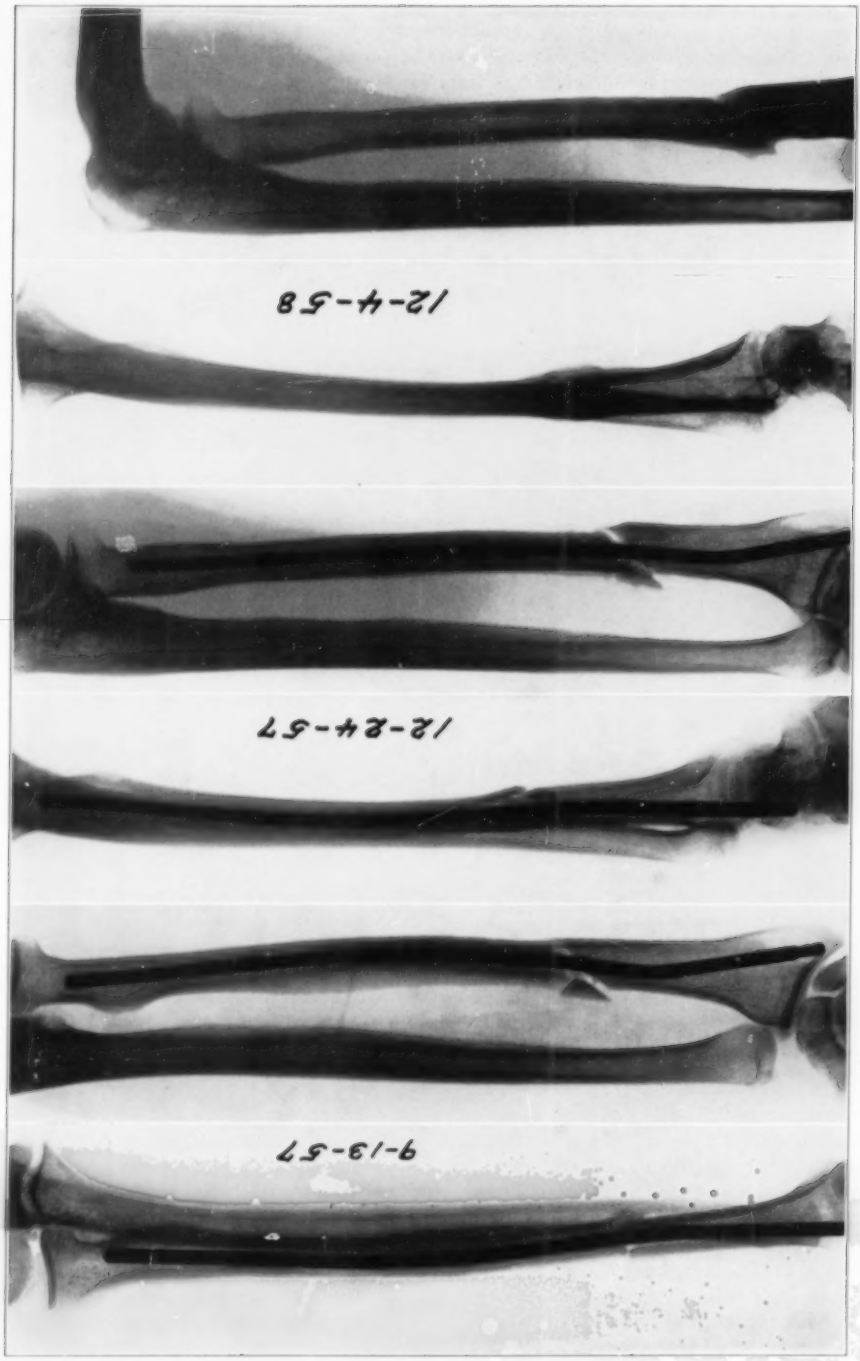


FIG. 15

Shortening occurred, with derangement of the distal radioulnar joint. Note how far the distal fragment has telescoped on the nail.

six months, 24.2 per cent in six months or more, and 55.1 per cent remained *in situ*.

Infection, as already mentioned, was mild in one open fracture, mild in one closed fracture, and severe in one closed fracture (Fig. 13), but in the last case an open draining wound was present in the knee, and the delayed infection in the arm was thought to be metastatic.

These complications are numerous, but with the knowledge they have provided they can now be circumvented for the most part.

TECHNIQUE OF INSERTION AND EXTRACTION OF THE NAILS

The technique of insertion is exacting. First and foremost, a full complement of radial and ulnar nails should be on hand, together with a combination driver and extractor (Fig. 7), a one-eighth of an inch drill-point, a reamer just under the

FIG. 16

The proximal one and one-half inches of the nail is now round in cross section, aiding insertion.

size of the nail, and a drill with a Jacobs chuck. General anesthesia and an upper-arm pneumatic tourniquet are preferred. Sterile preparation of the skin with appropriate draping of the arm from finger tips to tourniquet should be carried out, and the arm and hand covered with sterile stockinet. With the arm either on a side table, or across the chest, the ulnar fracture is exposed by the preferred incision, and the ends of the bone are exposed. The straight ulnar nail is then tested for fit, and if the canal is too small, it is enlarged first with the one-eighth of an inch drill bit and then with the reamer. When the small diameter of the canal is passed, the drill will suddenly slip further in. When both fragments have been reamed, of if the bone does not need reaming, the fracture is reduced, and an ulnar nail of correct length is selected by measuring it alongside the arm. The lengths of the ulnar nails are graduated in one-inch increments from nine to

eleven inches. The driver is then threaded on the nail, the elbow flexed to 90 degrees, and the nail driven retrograde up the proximal fragment of the ulna. As the cortex of the olecranon is approached, a change in the tone of the hammer blows is heard; at this point it is wise to place a sterile folded towel or pillow case beneath the humeral condyles. A few more firm hammer blows will drive the nail out the posterior aspect of the olecranon, and a one-centimeter incision is made through the skin over the nail. The nail is then driven further retrograde until its distal end is at the fracture site. At this point, the driver is moved from the distal to the proximal end of the nail. The fracture is reduced under direct vision, and the nail is then driven down the distal fragment until the driver is half an inch from the olecranon.

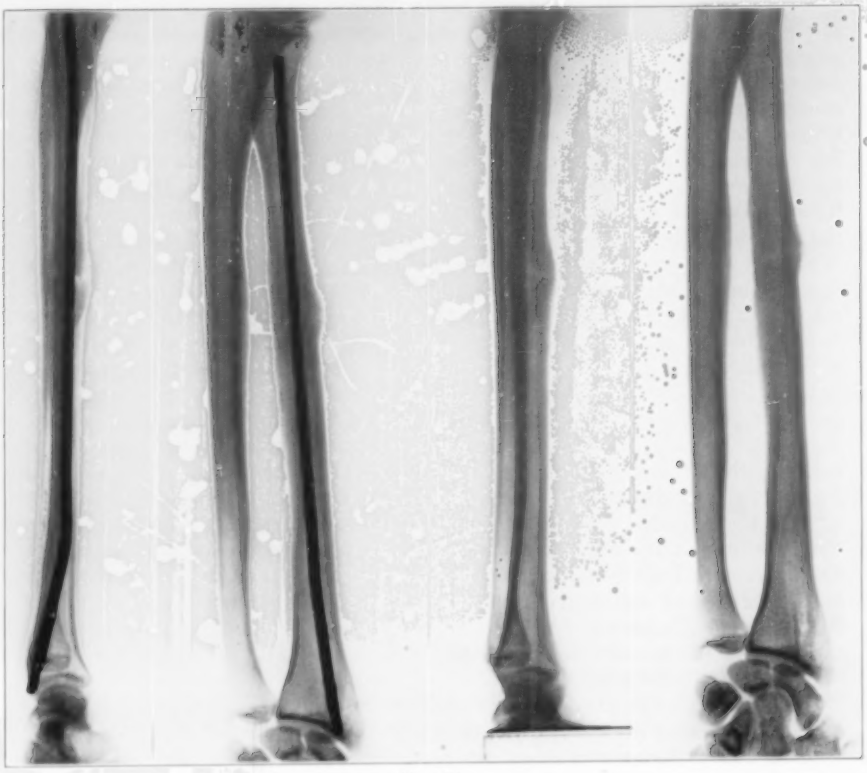


FIG. 17

This nail was inserted with the major arc in the dorsal direction. Since the interosseous space was not narrowed, no limitation of motion occurred.

Next, the fracture of the radius is visualized by an appropriate incision, and the bone ends are exposed. The size of the medullary canal is then checked for fit of the nail. If the canal is too small, it is reamed proximally and distally in the same fashion as described for the ulna. The fracture is reduced under direct vision, and a nail is placed along the radial border of the arm to determine the correct length. The nail should extend from the radial styloid to within half an inch of the radial head, or within one and one-half inches of the lateral epicondyle of the humerus. The lengths of the radial nails are graduated in half-inch increments from eight to eleven inches. The technique for driving the nail into the radius is similar to that described by Lottes for the insertion of the Lottes nail into the tibia [18]. The wrist is flexed and placed in ulnar deviation, which

pulls the tendons of the long abductor and short extensor of the thumb anterior to the radial styloid. A 2.5-centimeter longitudinal incision is next made extending 0.5 centimeter distally from a point proximal to the tip of the styloid process and 0.5 centimeter dorsal to its volar border. The incision is carried directly down to bone at its proximal level, but in its distal portion the incision is made to extend only through the skin. This serves to prevent the nail from traumatizing the skin in the process of driving. A small cruciate incision is next made through the dorsal carpal ligament, and the periosteum reflected from the radial styloid for a distance of 0.5 centimeter in all four directions. A drill hole one-eighth or three-sixteenths of an inch is then made through the exposed cortex on the radial styloid, with the handle of the drill first held perpendicular to the bone and then inclined distally as the drill point is rotated until the drill point is aimed at the lateral epicondyle of the humerus. Once through the cortex the drill is advanced for a distance of two to two and one-half inches. This procedure produces an oblong hole at the point of insertion and a channel of insertion which nearly parallels the distal part of the medullary canal. A nail of correct length is then placed in the same plane as the radius, so that the long arc of the nail parallels the long arc of the radius. With the wrist in flexion and ulnar deviation, the nail is inserted in a proximal direction by hand as far as possible. If it cannot be inserted two and one-half inches by hand, the angle of insertion is too acute; the nail should be withdrawn and the angle of insertion drilled more obliquely. When the nail can be inserted two and one-half inches by hand, the driver is threaded on the nail, and while the left hand exerts pressure on the nail to incline it toward the ulna, the right hand is used to drive in the nail. If marked resistance is met, the nail may be rotated back and forth a few degrees and then driven with moderately firm blows until it reaches the fracture site. The fracture is then reduced under direct vision again, and the nail driven into the proximal fragment until the distal end is within half an inch of the radial styloid. At this stage the wounds should be covered, and anteroposterior and lateral roentgenograms made (with sterile cassette covers). The full length of the radius and ulna should be included to make sure that the nails are not too close to the distal end of the ulna or the proximal end of the radius. If the nails are of satisfactory length, they are then driven in the remaining half an inch. During the final seating of the nails, each fracture site should be observed. If distraction occurs, the nails should be backed out until apposition is obtained. The tourniquet is then deflated, hemostasis secured, the wounds closed, and a long arm cast applied. Immobilization in the cast should be continued until roentgenograms show that union is progressing satisfactorily.

The nails should remain *in situ* until the bridging periosteal callus has consolidated; the general rule has been to remove them one year after their insertion. If before the end of a year it appears that interstitial callus is being delayed by the nail and that firm periosteal bone is bridging the fracture site, the nail should be removed. A general anesthetic is required, since the nails are firmly seated in the bone. Incisions are made over the threaded end of the nails at the olecranon and at the distal end of the radius, and the extractor is screwed onto the nails as far as possible. During extraction, the threads on the nails have occasionally been stripped; accordingly, the first blow on the extractor should be firm, to dislodge the nail from its original position. Lighter blows may then be used to complete the extraction. Vise-grip pliers should be available for use should stripping of the threads of the nail occur.

Indications

The straight triangular ulnar nail may be used in any diaphyseal fracture of the ulna, if proper precautions as to the size of the canal are observed.

The prebent triangular nail for the radius is indicated in diaphyseal fractures, except those in the proximal and distal fourths, when the medullary canal

measures not less than three millimeters in diameter in its smallest diameter at the mid-point of the shaft. If butterfly fragments are present, supplementary fixation by wire loops may be needed. The nail should not be used in bone that requires considerable reaming; the nail must engage the cortex firmly, and, if the cortex is too thin, the nail may split the shaft. When the canal of the bone is too large for firm fixation by the four-millimeter nail, the nail may still be used, but external immobilization until solid union is shown by roentgenogram is mandatory. Nails measuring five millimeters on each side have been made, but to date they have been used in only one radius; they appear to be too stiff, and it is anticipated that they will be more likely to fragment the cortex. In fractures of the distal and proximal fourths of the diaphysis, the nail should not be used, for then it cannot engage the cortex of the short fragment sufficiently to give rigid fixation. Furthermore, in the distal quarter of the diaphysis, a small canal will require reaming around both the dorsal and the radial curves. Since the reamer is not flexible, it will tend to pierce the cortex and make a point of exit for the proximal end of the nail when it is driven in.

SUMMARY

The history of medullary fixation, particularly of the forearm bones, is briefly reviewed.

Results are reported of a detailed study of the size and contour of the medullary canal of 100 radii from cadavera.

Medullary nails triangular in cross section have been devised for the forearm bones. The nail for the radius is prebent in accordance with anatomical data, and is made of a metal tempered to the proper resilience and rigidity.

Results are reported for the first fifty patients in whom these nails have been used. Despite some early clinical errors, and despite some serious preoperative complications, there were fewer instances of malunion in this series than we have been able to obtain with closed methods, and fewer instances of non-union than have resulted from other methods of open reduction.

The technique of insertion and extraction of the nails is described, and the indications given for their use in diaphyseal fractures. The technique is exacting, and if not properly performed may produce complications.

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DISCUSSION

Dr. Milton S. Thompson, San Antonio, Texas: Dr. Sage has had unusual opportunity to gain knowledge on this subject, for in 1955 he and Dr. Hugh Smith analyzed more than 500 forearm fractures treated by medullary fixation under the sponsorship of the Surgeon General of the Army. He states that he would agree that if a closed fracture of the forearm can be anatomically reduced by manipulation, and satisfactorily immobilized by plaster, that would be the preferred treatment, but if a satisfactory method of medullary fixation could be devised, it might become the preferred treatment. Is it not already a preferred treatment for those diaphyseal fractures of the ulna which require open reduction? I believe it is.

Medullary fixation of the radius should meet the following requirements:

1. It should be a simple method, with no undue risk of infection, delayed union, or tendon rupture, and no wide exposure, no extensive periosteal stripping, no end-to-end reaming, and no free mobilization of fragments.

2. It should provide anatomical reduction with preservation of normal bone curves, without the potentiality of keeping the fragments apart when absorption occurs.

3. It should provide stable fixation in both angulatory and rotational planes.

Dr. Sage's nail satisfies these demands, as attested to by the results he has reported. It seems to us, however, that we should demand more if a method of medullary fixation of the radius is to be as satisfactory as that for the femur:

(*Continued on page 1525*)

The Localization of Chloride in Epiphyseal-Disc Cartilage as Determined by Histochemical Techniques*

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In a previous paper [1] the position of chloride in articular cartilage obtained from puppies was described. A logical sequel to this investigation of joint cartilage is the application of the same methods and techniques to the hyaline cartilage of the epiphyseal disc. Epiphyseal cartilage was removed from anesthetized puppies, subjected to freezing-drying fixation, and then stained by the Gersh silver nitrate stain for chloride. The distribution of chloride in these sections of epiphyseal-disc cartilage is similar to the articular cartilage in that no chloride was seen within the chondrocytes. There is, however, a marked difference in the distribution of chloride within the matrix of these cartilages.

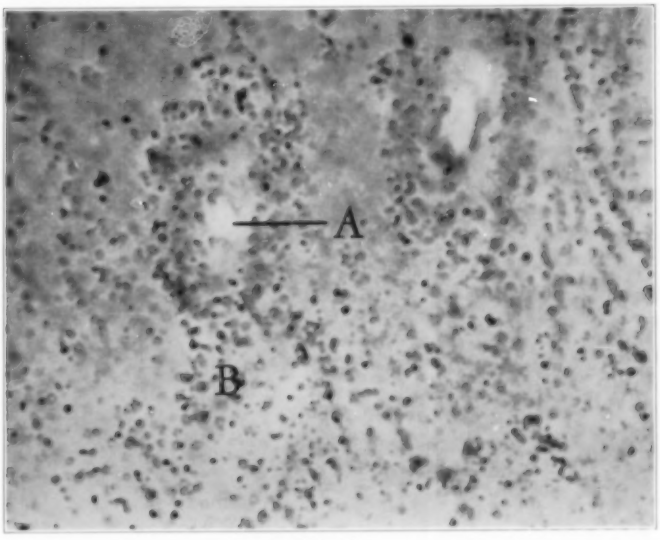

FIG. 1

Section of resting zone of epiphyseal disc: *A*, chondrocyte; *B*, matrix filled with granules representing chloride.

PROCEDURES

Two puppies, three months of age and appearing in normal health, were anesthetized with ether. Twelve specimens of the epiphyseal disc were taken by cutting through the epiphysis into the metaphysis with a scalpel. The specimens were obtained from the distal portion of the femora and proximal portion of the tibiae. The specimens of cartilage thus obtained were each approximately five millimeters long and one millimeter square. These specimens were placed at once in a freezing-drying apparatus, the same techniques being used as reported in

* This work was supported by United States Public Health Grant No. A 1443 (C-1).

the previous paper [1]. The dried specimens were then embedded in dehydrated paraffin (melting point, 58 degrees centigrade). Sections were cut at six micra and were about one millimeter square in size. The paraffin was removed with petroleum ether (boiling point, 60 degrees centigrade) which had been dried over metallic sodium. The mounted sections were stained with a 60 per cent silver nitrate solution and then exposed to an arc light until the brown granules became visible. Briefly, in the section, the silver ion of the solution unites with the chloride of the

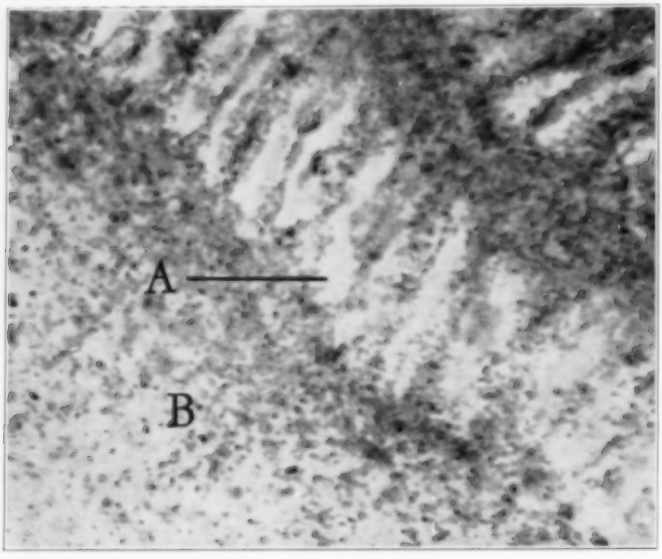

FIG. 2

Section of proliferating zone of epiphyseal disc: *A*, chondrocyte; *B*, matrix filled with granules representing chloride.

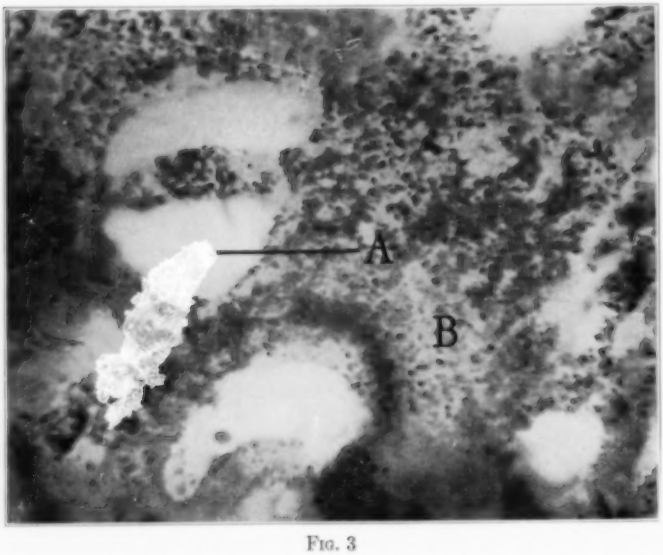

FIG. 3

Section of hypertrophic zone of epiphyseal disc: *A*, chondrocyte; *B*, matrix filled with granules representing chloride.

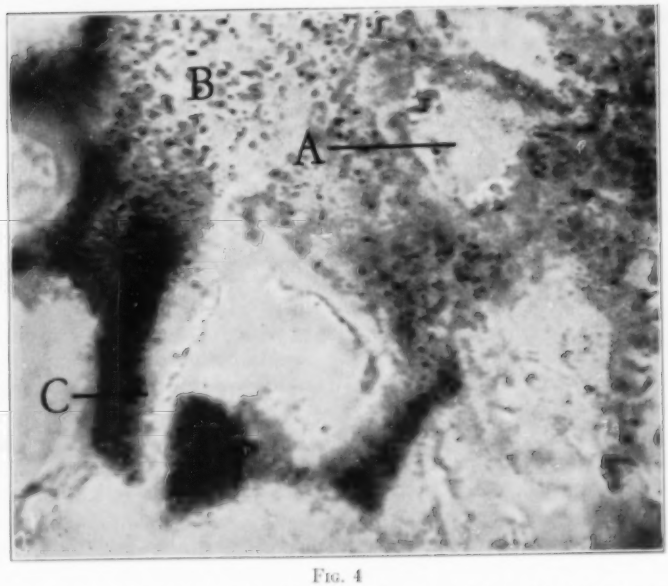

FIG. 4

Zone of provisional calcification. Note heavy staining of calcified area and invasion of cell by small blood vessel. *A*, chondrocyte; *B*, heavy staining matrix in area of calcified cartilage; and *C*, chondrocyte invaded by capillary.

tissue to form a silver chloride precipitate. The arc light reduces the silver chloride to silver oxide which is visible as brown granules.

RESULTS

Sections of epiphyseal-disc cartilage stained for chloride revealed two basic characteristics. In none of the sections were the granules seen within the chondrocytes. The granules in the matrix were distributed rather evenly throughout. This last observation differed markedly from articular cartilage in which the granules were clustered in the pericellular matrix.

A more detailed description of the chloride distribution can best be obtained by examining the areas into which epiphyseal-disc cartilage is usually arbitrarily divided. In the region of resting cells (Fig. 1) the chondrocytes are sparse and small. No granules were seen within the cells. The granules were thickly but evenly spread throughout the matrix. The zone of proliferating cells is morphologically characterized by closely packed flattened cells. The granule pattern (Fig. 2) does not differ from the previous zone. As the end of the cellular column is approached the zone of hypertrophic cells is reached. Here the granules in the matrix seem to become thicker, and there is a slight concentration of granules in the pericellular area (Fig. 3). This is similar to the halo formation seen in articular cartilage. The last area is the zone of provisional calcification (Fig. 4). As long as the lacunae remained intact no granules were seen within them. There is a marked increase in density of the granules in the matrix of this region. It corresponded to the region of calcified cartilage seen in these sections when stained with toluidine blue.

DISCUSSION

Epiphyseal-disc cartilage appears to contain chloride throughout the matrix in fairly even distribution. Although this method is not quantitative, these sections of epiphyseal cartilage stained more readily than sections of articular cartilage and the granules were seen throughout the matrix. The amount of extra-

cellular chloride reflects the amount of extracellular water. Young cells of many tissues are known to be surrounded by matrix containing a large proportion of interstitial water. Yannet and Darrow, in 1938, showed that in the soft tissues, muscles, and liver the extracellular water decreased in volume as the animal increased in age. Histologically, the individual tissue fibers increased in size as they crowded out some of the interstitial fluid. In 1958, Eichelberger, Akeson, and Roma observed a difference in the total water content of articular cartilage removed from puppies of different ages. As the puppies increased in age from six weeks to twenty-five weeks there was a decrease in the ultrafiltrate water and a large increase in the chondrocyte solids, indicating an increase in the number of chondrocytes. Since this tissue water is always isotonic with body fluids under normal conditions one would expect to find histologically large amounts of chloride surrounding the young cells. The chloride-staining characteristics of epiphyseal-disc cartilage, therefore, suggest that the chondrocytes are young and must have a very active metabolic rate—certainly more active than that of the chondrocytes of articular cartilage.

Eeg-Larsen estimated the life span of a chondrocyte in the epiphyseal disc of a rat to be thirty to forty-five hours. The difference in chloride-staining patterns in epiphyseal disc and articular cartilage may thus be explained by the obvious difference in function. Since epiphyseal-disc chondrocytes reproduce rapidly, they must have a higher metabolic rate and are short lived. Articular-cartilage chondrocytes are not reproducing at a rapid rate; they are existing at a comparatively lower metabolic rate, and apparently have a longer life span.

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Bone-Marrow Eosinophilia with Solitary Eosinophilic Granuloma of Bone

A Report of Two Cases

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From the Department of Pathology, Hospital for Joint Diseases, New York

This report deals with two cases of solitary eosinophilic granuloma. Attention will also be directed to the possible diagnostic significance of the finding of an increase in the eosinophil count of the bone marrow (sternal or iliac) in patients with this disorder. Green and Farber described the frequent lack of eosinophilia of the peripheral blood in this disease. It is of particular interest that in the patients presented here the eosinophil count of the peripheral blood was within normal limits, whereas the eosinophil count of the iliac-bone marrow was strikingly increased.

Case 1. The patient was a boy, three and one-half years of age, who first came to the hospital because of pain, of three weeks' duration, in the right arm. The pain had developed after a fall, with resulting injury to the arm. A roentgenogram made the day after injury showed a fuzzy radiolucent lesion associated with some periosteal new-bone deposition in the mid-portion of the shaft of the humerus (Fig. 1). The possibility, however, that the lesion might be an eosinophilic granuloma was not considered, and the arm was placed in a cast. The pain persisted, and another roentgenogram, made approximately three weeks later, revealed that the lesion had increased considerably in size (Fig. 2). It was now seen as a large focus of osteolysis which measured 5.5 centimeters in its long axis. There was also a striking parallel-layered onionskin-like periosteal new-bone formation. It was because of this change in the roentgenographic appearance of the lesion that the child was admitted to the Hospital for Joint Diseases.

Questioning of the mother failed to reveal anything unusual in the child's past history; there was neither past history nor family history of allergy. Physical examination of the child yielded entirely negative findings, except for those relating to the right upper extremity. Palpation of the arm revealed tenderness and definite thickening of the humerus extending along about two or three inches of the shaft. There was, however, no local heat or redness.

Since the child had been admitted to the hospital with the presumptive diagnosis of Ewing's sarcoma, roentgenograms of the skeleton, chest, and abdomen were obtained. All these were within normal limits.

Various clinical laboratory studies were carried out before the surgical intervention. These revealed no significant deviations from the normal findings for a subject of this age. Three stool examinations for ova and parasites were negative.

Biopsy was performed on August 15, 1958. When the lesion was entered, a large cavity was encountered from which only small bits of tissue could be curetted. The diagnosis of eosinophilic granuloma was established by microscopic examination of the curettements (Fig. 3).

Since I was aware of the fact that in patients with eosinophilic granuloma the eosinophilic count of the bone marrow may be elevated at sites remote from the granuloma[1], a study of the iliac-bone marrow was made.

The first bone-marrow aspiration was done three days after biopsy of the humerus. The iliac marrow at this time showed an eosinophil count of approximately 25 per cent (Fig. 4), a striking increase over the usual finding of from 1 to 2 per cent, with a normal range of from 0.5 to 3 per cent. Aside from the numerical increase in eosinophils, which is especially striking in the sections of marrow clot, morphological abnormalities and staining peculiarities were present in this cell series. There was remarkable variation in the size and number of cytoplasmic granules from cell to cell. Many eosinophilic myelocytes and metamyelocytes exhibited basophilic as well as eosinophilic granules. Some of these cells were unusually large, but others were small. Primitive reticulum cells, stem cells, and early granulocytic forms were relatively numerous. Histiocytes were increased. The pleomorphic quality described in connection with the eosinophils was also exhibited to some degree by cells of all series. Dr. Charles Emerson of Boston confirmed this description.

FIG. 1

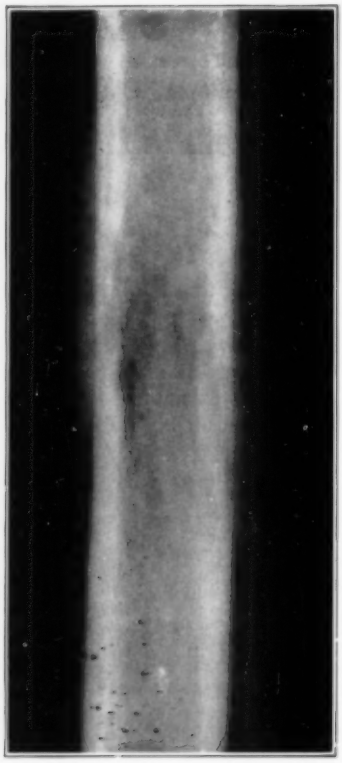

FIG. 2

Fig. 1: Case 1. Roentgenogram made on the day after injury demonstrates the fuzzy radiolucent area in the mid-shaft of the humerus, fracture, and periosteal new-bone formation.
Fig. 2: Roentgenogram made three weeks later shows the marked osteolysis and periosteal new-bone formation.

Concomitantly, the peripheral blood was also studied for possible deviations of the eosinophil count. It revealed a total eosinophil count of 344 cells per cubic millimeter and a total white-cell count of 11,200. The differential count was 35 per cent polymorphonuclear neutrophils, 59 per cent lymphocytes, 4 per cent monocytes, and 2 per cent eosinophils.

Thus, despite the high eosinophil count of the bone marrow of the ilium, the eosinophil content of the peripheral blood was within normal limits.

The finding of approximately 25 per cent eosinophils in the bone marrow in this patient is in sharp contrast to what one observes under normal conditions. It is of interest that the repeat marrow eosinophil counts two weeks and one and one-half months later were 10 per cent and 15 per cent, respectively. This would seem to exclude any transient effect from the operation. Indeed, the stress of operation usually results in a fall in eosinophils in the peripheral blood [6].

CASE 2. This patient was a Brazilian man, thirty-one years old, who entered the hospital with a swelling, of eighteen months' duration, of the left mandible. There was no history of allergy, and no ova or parasites were found in his stools. Biopsy established the diagnosis of eosinophilic granuloma. A preoperative bone-marrow eosinophil count was approximately 15 per cent, whereas the peripheral blood showed 5 per cent eosinophilia. The total white-cell count was 13,400 cells per cubic millimeter, and the total eosinophil count in the peripheral blood was 625 eosinophils per cubic millimeter.

DETERMINATION OF THE BONE-MARROW EOSINOPHILS

The use of fresh smears is not desirable since pulling the slides often results in an uneven distribution and lysis of eosinophils. Two methods were employed in the cases reported here.

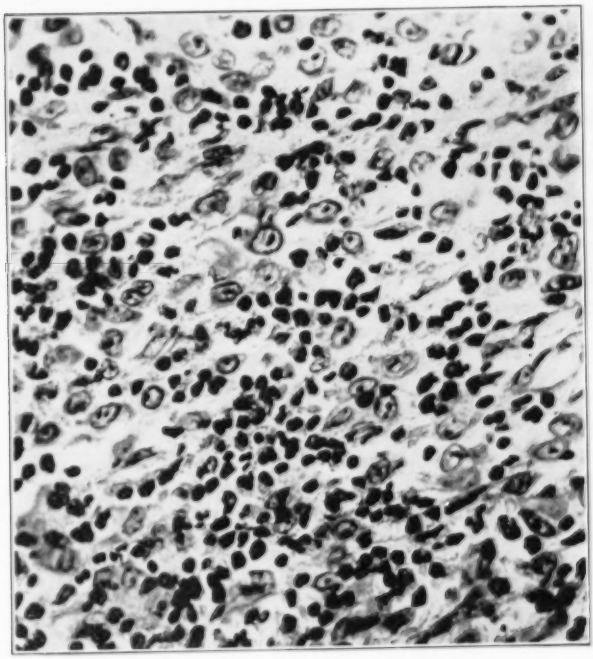

FIG. 3

Biopsy of the lesion of the humerus demonstrating the marked histiocytic response and the infiltration of bilobed nuclei (× 325).

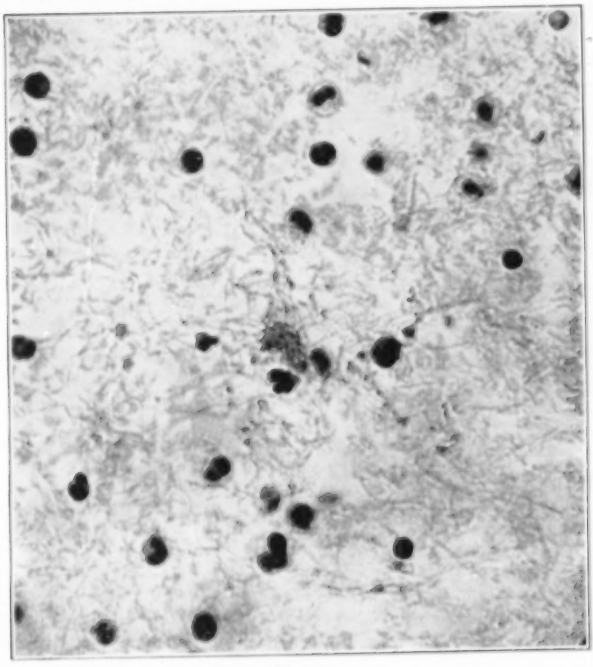

FIG. 4

Microscopic section of the iliac-bone-marrow clot showing the high proportion of bilobed nuclei (× 500).

The first method was to count clotted and fixed marrow sections. This was correlated with the second method which was worked out and used with the first patient (Case 1) one and one-half months after operation.

In the second method the technique is similar to the Randolph method [7] of counting total circulating eosinophils per cubic millimeter in peripheral blood, using an aqueous solution of propylene glycol and phloxine. First, however, one volume of the heparinized marrow blood is mixed with an equal volume of the phloxine and propylene glycol solution in order to dissolve the droplets of marrow fat which would otherwise clog the diluting pipettes. Without the fat droplets present, the heparinized marrow blood can then be treated in the usual manner to obtain a total eosinophil count of the marrow.

The same technique can be used to count the total white cells in the marrow per cubic millimeters by combining the marrow blood (which has had its fat droplets removed) with the usual white-cell diluent and counting the cells in the same fashion as for the peripheral blood.

This method was used on several controls with entirely normal findings. When used on the first patient reported here one and one-half months after operation, a total marrow eosinophil count of 5,800 cells per cubic millimeter and a total marrow white-cell count of 38,300 per cubic millimeter were found, and an eosinophil count of 15.6 per cent. This checked well with the eosinophil count on the clotted and fixed sections, which was approximately 15 per cent.

DISCUSSION

The main object in this presentation is to point up the fact that in cases of eosinophilic granuloma of bone, the bone marrow findings at a site remote from the bone lesion may yield a high eosinophil count. Farber, in 1941, mentioned that the stimulation of bone marrow was so marked in some instances that the diagnosis of myelocytic myeloma was excluded only with difficulty.

There are, of course, unrelated diseases which may elevate the eosinophils of the bone marrow, such as allergies, parasites, and leukemia. These must be excluded in patients with eosinophilic granuloma.

In their original report on eosinophilic granuloma of bone, Lichtenstein and Jaffe mentioned the fact that in this condition the eosinophil count of the bone marrow may be increased in spite of a normal peripheral count.

My present interest in eosinophilia of the bone marrow in cases of eosinophilic granuloma was originally stimulated by Dr. Charles Emerson, of Boston, who brought a case to my attention in 1957. In that patient the eosinophilic granuloma was in a rib, and the bone-marrow eosinophilia exceeded 10 per cent. Eosinophilia of the bone marrow in association with an eosinophilic granuloma of the lung was also noted by Livingston; in this patient the peripheral blood showed no elevation of the eosinophil count.

The possible connection between the decrease in the bone-marrow eosinophilia and the ultimate prognosis of a patient with eosinophilic granuloma seems worthy of further investigation.

SUMMARY

An elevation of the eosinophils in the differential count of the bone marrow was found in the two patients presented in this paper (and in the three others mentioned). This was in sharp contrast to the peripheral-blood studies which revealed no remarkable deviation from the normal counts expected.

Bone-marrow findings as described in this paper may be helpful in leading one toward the diagnosis of eosinophilic granuloma.

A new method of counting eosinophils in the bone marrow is described and can be used to check counts done by smear or clotted and fixed marrow sections.

NOTE: The writer wishes to acknowledge his appreciation to Dr. Henry Jaffe for his help in reviewing and in making suggestions concerning this paper.

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DISCUSSION

Medullary Fixation of Fractures of the Forearm

(*Continued from page 1516*)

1. The fixation should provide a degree of stability which would render external fixation unnecessary.

2. It would be of advantage to use a straight nail, not only for ease of insertion, but because straight nails can be cut to proper length at the table, thus obviating the necessity for the full complement of sizes (six ulnar and fourteen radial nails).

Dr. Sage stated that in a previous series a Rush type of nail, modified to triangular cross section, was used, but was found unsatisfactory. For the past four years, however, such a nail has been used at Walter Reed Army Hospital, and found to be extremely satisfactory.

Inserting a nail through the radial styloid requires a lot of curves—an S-curve at least. The point at first must bend away from the opposite cortex to enter the medullary cavity and then bend toward it, to stay there. Dr. Sage states that in thirty-two cases he inserted the nail through the dorsum of the radius, at a point at the radial side of Lister's tubercle.

At Walter Reed Hospital, roentgenograms were made of radii of 121 cadavera with a metal marker at Lister's tubercle. Straight lines drawn through this landmark into the proximal head indicated that the radial medullary curves in both planes were more apparent than real, and presented no more problem for a straight nail than does the minor curve of the femur.

Accordingly, nails were inserted at a point just proximal to Lister's tubercle. In this area there is a wide space between the extensor pollicis longus and the radial wrist extensors and enough soft tissue to cover the seated nail. A small transverse incision in the grain of the skin is used; the styloid insertion requires a longitudinal incision.

Dr. Sage discontinued his dorsal insertion because of three cases of spontaneous rupture of the extensor pollicis tendon. This complication did not develop in the patients at Walter Reed Hospital, which would lead us to wonder whether this complication might have some other cause than the dorsal insertion *per se*.

Dr. Sage (closing): Dr. Thompson doesn't realize that when we were using the radial side of Lister's tubercle we bent a fourth curve in that nail. We felt that if the nail was going to be inserted from the top of the bone it should have a dorsal curve in it, in order to prevent pushing down in the medullary canal.

We also backed up a little proximally from Lister's tubercle, about a quarter of an inch. Dr. Thompson stated that he felt we would have to have six ulnar nails and fourteen radial nails as the full complement, but the nails may be used interchangeably for each arm—three for the ulna and seven for the radius; those for the radius are graduated in half-inch increments, and those for the ulna are graduated in one-inch increments.

I do not say that our nail, which I regret has my name on it, is the answer. I thought it out with the anatomical study and I hope that, with publication, someone else will be able to improve on our method of medullary fixation.

Aneurysm of the Popliteal Artery Caused By Osteochondroma of the Femur*

BY FRANK R. DENMAN, M.D., THOMAS O. SHINDLER, M.D., JAMES HAMPTON, M.D., AND LEROY HANSON, M.D., HOUSTON, TEXAS

From the Department of Surgery and Orthopaedic Surgery, Hermann Hospital and Shriners' Crippled Children's Hospital, Houston

Aneurysms, pulsating hematomata, and arteriovenous fistulae with aneurysmal dilatation frequently result from penetrating wounds of the extremities. Popliteal aneurysms most commonly are due to arteriosclerosis. On the other hand, peripheral arterial aneurysms, due to trauma from adjacent osteochondromata, are rare. A review of the literature revealed only three reported cases.

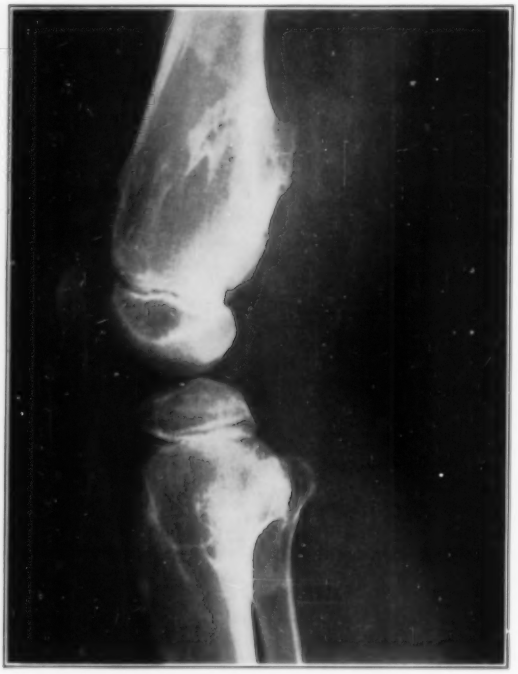

FIG. 1

Roentgenographic appearance of osteochondroma.

Hudson reported the occurrence of a false aneurysm in a fourteen-year-old boy, after vigorous bicycling. The aneurysm was the result of penetration of the popliteal artery by one of multiple exostoses. A single rent in the popliteal artery was repaired, and a good result was obtained. Lesser and Greeley reported the occurrence of an arteriovenous fistula and aneurysm of the lower segment of the femoral artery associated with an osteochondroma of the femur. At surgery, an osteochondroma was found to be penetrating the aneurysmal sac, which contained both arterial and venous communications. The defect in the femoral vein was closed with a portion of the aneurysmal-sac wall. The femoral artery was repaired

* Supported in part by The Houston Heart Association.

by end-to-end anastomosis after proximal mobilization of the artery and flexion of the knee. A good functional result was obtained. Paul reported a case of a false aneurysm of the popliteal artery which resulted from penetration of that artery by one of multiple osteochondromata. The patient was a man, twenty-two years old, who gave a history of painful swelling of the knee of seventeen days' duration. In this case, the aneurysmal sac was removed, and the arterial injury was repaired by suturing the perforation. Postoperatively, the patient could walk without difficulty, although no pulses were palpable below the level of injury.

A nine-year-old white boy had been observed at the Shriners' Crippled Children's Hospital for six years for multiple congenital osteochondromata involving the ribs, clavicle, and long bones. He had had no serious difficulty until three months prior to admission, at which time he complained of pain in the right popliteal area. Immediately prior to the onset of pain, he had participated in vigorous physical activity at a local boys' club. He continued to have intermittent pain, but was not seen by a physician for six weeks after the initial episode. At that time, a definite tumor was palpable in the right popliteal fossa, which was firm, fixed, and non-tender. No thrill or bruit could be detected. There were good pulsations in both the dorsalis pedis and posterior tibial arteries, but

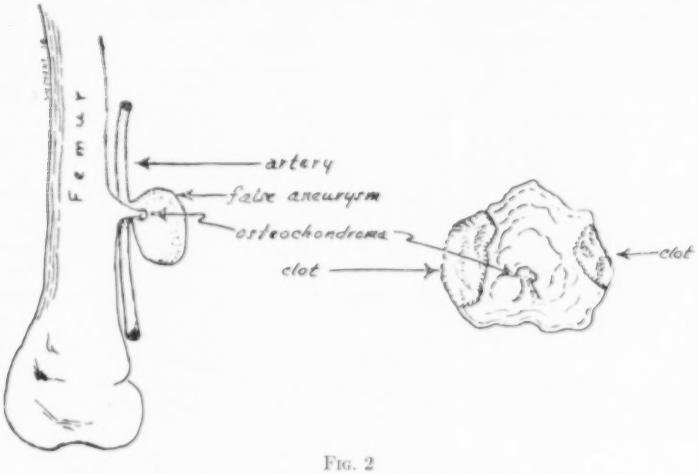

FIG. 2
Diagram showing osteochondroma penetrating aneurysmal sac.

no pulsation of the mass itself. The leg was not increased in length or in diameter. There was no restriction of motion but some pain was present on full flexion of the knee. Roentgenograms showed a four-by-three-centimeter osteochondroma on the posterior surface of the distal ends of the femora just above the adductor tubercle. The provisional diagnoses were: (1) cyst of the knee-joint capsule, (2) a bursa overlying the osteochondroma, and (3) a bursa connecting with the anserine bursa of the knee joint. The patient was seen by the members of the orthopaedic staff, and it was agreed that the cyst should be excised. Accordingly, on July 25, 1958, the patient was taken to the operating room, and an L-shaped incision was made, beginning on the lateral aspect of the thigh overlying the biceps femoris tendon and extending transversely across the posterior surface of the popliteal space. The dissection was carried down to the deep fascia of the popliteal space which was incised, and the mass was exposed to view. A tourniquet had been applied in the usual fashion to the thigh above and no pulsations were observed; however, in view of the dark discoloration of the mass, a needle was inserted into it and bright-red blood was obtained. The tourniquet was then released and vigorous pulsations of the mass were observed. A diagnosis of popliteal aneurysm was made, and after consultation with a vascular surgeon, the incision was closed. A few days later, a femoral arteriogram was made, which showed filling of the superficial femoral artery above and below the mass, and a little of the opaque medium within the mass itself. The L-shaped lateral incision was allowed to heal, and approximately four weeks later, on August 22, 1958, the patient was returned to the operating room, where, without a tourniquet, a six-inch, S-shaped incision was made beginning over the medial aspect of the lower right thigh and extending across the popliteal fossa. A saccular aneurysm of the popliteal artery was again disclosed and dissected free from the surrounding tissues, after tapes had been applied to the femoral artery proximally and to the popliteal artery distally. The popliteal vein was not involved. The aneurysmal sac was opened and an organ-

ized hematoma was removed revealing a spine of the osteochondroma to be projecting into the sac through its anterior wall. The sac was dissected free and excised. The resulting two-centimeter defect in the popliteal artery was repaired by end-to-end anastomosis by use of interrupted 00000 arterial silk. The exostosis of the femur was then removed and the bone edges smoothed. Fat and fibrous tissue were sutured over the raw bone surface to further protect the artery. After wound closure, the knee was immobilized in slight flexion. Good pulses were present in the foot at the completion of the operation. The knee was gradually brought out into full extension in a series of plaster casts over a period of two weeks postoperatively. Ambulation and full extension at this time resulted in no diminution of the pedal pulse volume. In spite of delaying the second operation for four weeks, a small area of marginal necrosis of the skin flap occurred, but this soon healed.

In November 1958, the patient was readmitted to the hospital and the osteochondroma of the opposite distal femur was removed as a prophylactic measure. At this time, the circulation in the right foot was excellent. He was last seen in June 1959; pulses were present and he had no complaints.

COMMENT

Popliteal arterial injury, due to penetration of a distal femoral osteochondroma, is rare. From comparison of the four known cases, it is noted that when such an injury occurs, a fase aneurysm or a pulsating hematoma, with an arterial communication, is most likely to be produced. The femoral popliteal arterial segment is the most common site of injury, and most of these injuries seem to follow some type of vigorous exercise. Aneurysms of the femoral popliteal arterial segment rarely constitute a hazard to the patient, because of rupture and hemorrhage, but most frequently become filled with laminated thrombus and ultimately result in sudden acute arterial occlusion endangering the viability of the foot and leg. Frequently, before complete occlusion occurs, multiple peripheral emboli to the distal portions of the extremity occur as a result of dislodgment of small particles from the main mother thrombus within the aneurysmal sac.

The differential diagnosis of a cystic mass in the popliteal space in patients who have osteochondroma of the distal end of the femur should include the possibility of a femoropopliteal aneurysm. Surgical excision with restoration of arterial continuity should be accomplished without delay in order to prevent the occurrence of serious ischemia of the leg or foot.

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Report of the Visit of the 1959 North American Traveling Fellows to Great Britain

The Traveling Fellowship Program officially began on April 7, 1959, at the Columbia University Club, in New York City, with the assembly of the five Fellows: Dr. John P. Adams, Washington, D. C.; Dr. Gordon W. Cameron, Edmonton, Alberta, Canada; Dr. Sherman S. Coleman, Salt Lake City, Utah; Dr. Andrew H. Crenshaw, Memphis, Tennessee; and Dr. James S. Miles, Denver, Colorado. Dr. Edward M. Winant and Dr. Lee Ramsay Straub were hosts at a send-off dinner, and on the following morning we boarded the Queen Mary for our trip to England. The trip was pleasant and provided the opportunity for us to become further acquainted and to make plans for the coming tour.

The North American Traveling Fellows for 1959 photographed at the Nuffield Orthopaedic Centre, Oxford. Left to right they are: Sherman S. Coleman, John P. Adams, Gordon W. Cameron, James S. Miles, and Andrew H. Crenshaw.

April 13

We arrived at Southampton and were met by Mr. Norman Capener, President of The British Orthopaedic Association; Mr. J. Crawford Adams, Honorary Secretary of The British Orthopaedic Association; Mr. F. G. St. Clair Strange; and Mr. J. S. Ellis. Dr. Howkins, of the British Railway System, and Mr. Dudney, Assistant Superintendent of Docks, expedited our trip through Customs, and within a short time we were aboard a first-class coach bound for London.

The day was beautiful and the temperature was in the 70's. The ride through the countryside between Southampton and London gave us our first glimpse of the green, well tended farm lands and the traditionally magnificent gardens. We arrived in London in the evening, and, as we passed Big Ben, the hour of six was striking. Our rooms were in the Mandeville Hotel, and later that evening we were guests at the Royal College of Surgeons, where we banqueted in the Council Room of this venerable institution. Our hosts were Mr. Capener and many of the senior orthopaedists of the London area.

April 14

Our first official hospital visit was to the London Hospital. The morning began with our participation in the weekly staff conference. We saw many interesting problems which were discussed by Sir Reginald Watson-Jones, Mr. H. Osmond-Clarke, and Mr. W. Alexander Law. After a sumptuous luncheon, we attended the operating-room theatre to view an arthrodesis of the hip performed by Sir Reginald Watson-Jones, a Putti-Platt operation on the shoulder by Mr. Osmond-Clarke, and a cup arthroplasty of the hip of the Smith-Petersen type by Mr. W. Alexander Law.

April 15

We visited St. Bartholomew's Hospital, where the senior consultant emeritus, Mr. S. L. Higgs, told us of St. Bartholomew's history. This is the oldest hospital in London and has the oldest established orthopaedic department. This was a day of excellent short essays presented by Mr. H. Jackson Burrows and his staff. Among the papers of unusual interest were those of Dean Nash, of the Medical School, on the problems of spina bifida in children; of Mr. W. D. Coltart, on manipulation of joints; and of Mr. G. W. Taylor, of the general surgical staff, on lymphedema. We visited the archives of the hospital and after the clinical day we toured the Tower of London and were shown the Crown Jewels by their keeper, General Sitwell. That evening we were entertained at dinner at the Prospect of Whitby.

April 16

Mr. T. T. Stamm and Mr. J. S. Batchelor were our hosts at the New Cross Hospital, the Orthopaedic Unit of Guy's Hospital. The first part of the day was spent in an operating-room session. Mr. Batchelor performed a laminectomy for a herniated nucleus pulposus. He utilized the side-lying position and emphasized the need for an ample exposure and complete laminectomy without interfering with the articular facets. Spine fusions are done rarely, and the patient is allowed to walk on the day after surgery. Another operative procedure of great interest was a bunionectomy performed by Mr. Stamm, in which he combined the Keller and McBride operations with an osteotomy of the base of the first metatarsal. Mr. Batchelor favored arthrodesis of the first metacarpophalangeal joint in the treatment of bunions. The afternoon was spent in ward rounds and in clinical discussion. In the evening we were entertained at a delightful dinner at The Cheshire Cheese.

April 17

Mr. Burrows, Dean of the Post-Graduate School, again was our host, in the absence of Mr. H. J. Seddon, at the Royal National Orthopaedic Hospital. The first discussion was on microradiography of normal bones which was presented by Dr. Colin Woods and Dr. Jowsey. Mr. K. I. Nissen discussed intertrochanteric myelotomy and McMurray osteotomy for primary osteo-arthritis of the hip. This was our first opportunity to see a large number of patients treated by the McMurray osteotomy for painful hips, and we were greatly impressed by Mr. Nissen's excellent results. It is his contention that interruption of the blood supply to the femoral head is probably the reason for the relief of pain and improvement in function.

In the afternoon we visited the country branch at Stanmore. Dr. John Scales discussed the corrosion of metal implants and told us that it is his conclusion that the least reactive metal today is Vitallium. Ward rounds were conducted by Mr. David Trevor, who informally discussed congenital dislocation of the hip. Later, we visited the research laboratory. The evening was spent in the home of Mr. and Mrs. P. H. Newman, where a delicious buffet dinner was served.

April 18 and 19

These were days of sightseeing in London. Superintendent Morley, of the River Police, conducted a tour of the Thames. This trip had been arranged by Mr. Charles Manning, of the Royal National Orthopaedic Hospital. After lunch at the Cutty Sark Tavern, we visited the Royal Naval College at Greenwich and were guided through by Captain St. John Cronyn, who also had conducted the tour of the previous group of Traveling Fellows. We toured the Cutty Sark Museum and went aboard that famous sailing ship.

On Sunday we witnessed the Changing of the Guard at Buckingham Palace and later walked through the many beautiful parks of central London.

April 20

At St. George's Hospital our hosts were Mr. G. C. Lloyd-Roberts and Mr. R. H. Young. In the morning we attended an operating-room session and saw Mr. Young perform a laminectomy for a nucleus pulposus and Mr. Lloyd-Roberts perform an open reduction of a congenital dislocation of the hip. Mr. P. R. French, Senior Registrar, gave us an interesting presentation of the experience of the staff at St. George's Hospital in the care of chronic knee problems in the older-age groups. He pointed out the frequency of the degenerative lesions of the menisci in patients with chronic knee complaints who do not often exhibit

the classic signs of meniscal derangement. In the afternoon we visited the Hospital for Sick Children, in Great Ormond Street, where clinical papers were presented by the consultant staff and registrars. Mr. Lloyd-Roberts discussed the behavior of the epiphyses in osteomyelitis of the newborn infant. He felt that despite roentgenographic appearance of complete destruction of the epiphyses of the knee and hip, many of these epiphyses will re-form. He also pointed out that in cases of pyarthrosis of the hip in which the epiphysis appears to be destroyed and the hip dislocated, many hips can be saved by open reduction and gentle handling, not unlike that in congenital dislocation of the hip. Mr. Lloyd-Roberts escorted us to the train in the afternoon, and at Faversham we were met by Mr. St. Clair Strange.

April 21 and 22

Our stay in Canterbury was divided into visits to the Royal Sea-Bathing Hospital, in Margate, and the Kent and Canterbury Hospital, as well as to the beautiful Kent countryside nearby. The scientific portion of our program consisted of excellent short clinical papers and ward rounds by Mr. St. Clair Strange, Mr. P. R. Wright, and Mr. R. C. Baird, who were ably assisted by their registrars. We also had the privilege of visiting Canterbury Cathedral, Dover Castle, and Dover. In the evening we dined at the Falstaff Inn.

Our next stop was at Oxford, where we were housed in Senior Fellow Rooms at Worcester College and Oriel College.

April 23, 24, 25, and 26

At Oxford we were the guests of Professor J. Trueta and staff of the Nuffield Orthopaedic Centre and attended the regular weekly staff conference, in which we participated. Professor Trueta gave us a history of the Centre and told us of their work in the current field of investigation. The studies they are now conducting are on (1) the blood supply of the femoral head in different age groups; (2) the mechanism of bone formation by the use of the electron microscope; (3) arthritis; and (4) problems of growth. In addition, there were several excellent discussions by members of the consultant staff. Of particular interest were Mr. E. W. Somerville's presentation on congenital dislocation of the hip and Mr. J. C. Scott's, on scoliosis. Mr. Somerville emphasized his belief that dislocation of the hip at birth is a rare phenomenon and only associated with certain teratological diseases. He also discussed the mechanisms by which the hip is dislocated in infancy. An interesting side trip while in Oxford was our visit to Blenheim Palace and Gardens at Woodstock, where we were the guests of the Duke and Duchess of Marlborough.

On Saturday we visited the Stoke Mandeville Spinal Injuries Centre, where Dr. L. Guttmann gave an impressive presentation on the results in the treatment of spinal-cord injuries. The excellence of their program is reflected in the high percentage of patients who are rehabilitated to gainful occupations. Dr. Guttmann is extremely conservative in his approach to the management of spinal injuries and has developed a meticulous technique for the handling of these patients. He also has gained world-wide recognition for the initiation of the Olympic Games for paraplegic patients. In the afternoon we visited the Royal Buckinghamshire Hospital at Aylesbury, where Mr. G. Platt discussed the common orthopaedic problems seen in this provincial orthopaedic centre.

On Sunday, after a tour of Oxford University, we drove to Stratford-on-Avon. Here we spent two delightful days and had rooms at the Shakespeare Hotel.

April 27

In the evening, we saw a performance of *Othello* in the magnificent Shakespeare Memorial Theatre.

April 28, 29, 30, and May 1, 2, and 3

On April 28 we traveled by train to Torquay for the Spring Meeting of The British Orthopaedic Association held with the French and Belgian Orthopaedic Societies. The meeting lasted five days, from April 29 through May 3.

The papers presented at the Orthopaedic Meeting will be reported in *The Journal of Bone and Joint Surgery*, British Volume. Of particular interest to us were symposia on slipped upper-femoral epiphyses and on cerebral palsy. Our group was represented at this meeting by Dr. James S. Miles, of Denver, who gave a preliminary report on his work in measuring the intramedullary pressure of bones particularly that of the femoral head.

After the meeting we traveled by train to Bristol. We were met by Mr. K. H. Pridie and Mr. A. L. Eyre-Brook and were guests in the homes of the members of the consultant staff.

May 5 and 6

We first visited the Winford Orthopaedic Hospital, where informal ward rounds and discussions were held. Later, we were shown the museum of Mr. E. W. Hey Groves, and Mr. Pridie exhibited to us many of Mr. Hey Groves' instruments. Of special interest among this

group of memorabilia was an ivory intramedullary femoral prosthesis which had been successfully utilized by Mr. Hey Groves. This resembled in detail many of those in use today.

On Tuesday we visited the Bath and Wessex Orthopaedic Hospital, a rheumatology center, where Mr. James Bastow and the staff presented an impressive variety of cases emphasizing, in particular, the indications and values of arthroplasty and synovectomy in rheumatoid joints. Dr. Gibson also gave a well illustrated lecture on the pathology of synovial lesions.

May 7

In Liverpool we visited the historic Liverpool Medical Institute which houses the Hugh Owen Thomas and Robert Jones Library. Professor B. L. McFarland was our moderator at the Institute, where many interesting and instructive clinical papers were presented. The afternoon was spent in a clinical session at the Royal Southern Hospital, where many out-patients were shown and their lesions and treatment discussed.

May 8 and 9

While in Oswestry our visit was interrupted by a visit to the Rolls-Royce Works, at Crewe, which had been arranged by Mr. Robert Roaf, Mr. Lloyd Griffiths, and Mr. T. McSweeney. The afternoon was spent in a well attended clinical conference at the Robert Jones and Agnes Hunt Orthopaedic Hospital.

We were over-night guests of the orthopaedic consultants in their homes. On the following morning we attended clinical rounds which were held on the wards.

May 10, 11, and 12

Mr. Lloyd Griffiths drove us to Manchester on Sunday through beautiful North Wales, and we stopped for lunch in historic Chester.

On Monday, at the Manchester Royal Infirmary, members of the teaching departments of medicine, rheumatology, orthopaedic surgery, and pathology each presented papers of orthopaedic interest. Notable among the many excellent presentations was a dissertation by Dr. J. Sharp and Dr. J. Ball on rheumatoid arthritis of the cervical spine.

Mr. Lloyd Griffiths reviewed the functioning Accident Service of the Manchester Royal Infirmary. He said that 60 per cent of the accidents seen occur in homes and on athletic fields and that approximately 350 Colles' fractures are treated yearly.

At the Park Hospital, in Davyhulme, Mr. John Charnley discussed his conception of compression arthrodesis and performed an arthrodesis of the knee and hip for us. In the afternoon he conducted a selected out-patient clinic.

May 13, 14, 15, 16, 17, and 18

We arrived in Glasgow after driving through the beautiful lake district.

On Monday we were guests of Mr. Alexander Miller at Philipshill Hospital. This center is an out-patient rehabilitation unit sponsored by the miners' union.

Tuesday was spent with Mr. James Patrick and staff at the Glasgow Royal Infirmary. The morning was devoted to ward rounds, and in the afternoon several clinical papers were presented by the staff. One paper of unusual scope dealt with the study of forty-three proved cases of herniation of the nucleus pulposus in adolescents. The author of the paper, Mr. A. McDougall, stressed the paucity of clinical symptoms and the absence of neurological changes. The primary signs of disc prolapse in adolescents are a stiff back and hamstring spasm. Many of the children presented a prolapse of the entire disc, and complete blockage was shown by myelogram.

At the Royal Hospital for Sick Children we were the guests of Mr. Noel Blockey. Several controversial problems in children's orthopaedics were presented for discussion. One problem in particular was avascular necrosis of the head of the femur, especially the means by which this could be detected early so that some form of treatment could be instituted. At the conclusion of this discussion, we were convinced that difference of opinion flourishes in Great Britain as well as in the United States.

That afternoon found us on the banks of Loch Lomond, where we spent a refreshing week end at the beautiful Lomond Castle Hotel.

On Monday we returned to the profession of orthopaedics at Killearn Hospital, Glasgow, as guests of Professor R. Barnes. After a series of provocative papers—including such topics as fractures of the femoral neck, perilunar dislocations of the wrist, and the management of compression injuries of the forearm—Professor Barnes concluded with his concept of the management of tuberculosis of the major joints. In the afternoon we drove to Edinburgh, where we were met by Professor J. I. P. James and Mr. George Mitchell.

May 19, 20, and 21

We attended a clinical meeting at the Edinburgh Royal Infirmary. The morning program included papers on the immune response of bone autografts and homografts by Mr. Chalmers, Dupuytren's contracture by Professor James, leg-lengthening procedures by Mr. W. V. Anderson, and arthroplasty of the elbow in rheumatoid arthritis by Mr. D. L. Savill. The pres-

entations evoked a great deal of discussion. We were honored with a luncheon in the Senate Room through the courtesy of the Principal of the University of Edinburgh and during the afternoon we were taken on a tour of the border country by the consultant staff. Included in the tour was a visit to Sir Walter Scott's home, where we were shown through his house by his granddaughter (five generations removed), Miss Jean Maxwell Scott.

At the Princess Margaret Rose Hospital an operative program was prepared for us. Professor James performed a flexor-tendon graft. Mr. W. V. Anderson did a leg-lengthening procedure which is extensively used at this hospital, and he emphasized its indication for paralyzed extremities. He stated that it is never indicated on an extremity that is shortened for other reasons, with the exceptions of congenital absence of the fibula and of one which has a normal musculature. The lengthening is now performed by means of a transverse osteoclasis, after drilling a few holes in the bone through a stab wound. The bone is gradually elongated in the usual manner. At the clinical session in the afternoon several interesting papers were presented. One provocative discussion was by Mr. Ian Paterson on the open reduction and internal fixation of fractures of the head of the radius.

That evening we were the guests of the Edinburgh Orthopaedic Club group at the Royal College of Surgeons of Edinburgh. We were honored by the presence of Sir Walter Mercer at this dinner.

No formal program was arranged for Thursday, and some Fellows chose to stay in Edinburgh to visit again the Princess Margaret Rose Hospital; others seized the opportunity for a round of golf at the Royal and Ancient Golf Club at St. Andrews. In the evening we traveled by train to Dundee, where we were met by Mr. I. S. Smillie, Mr. J. Hutchison, and Mr. I. D. Sutherland.

May 22 and 23

In Dundee we visited the Royal Infirmary and had the opportunity to see Mr. Smillie perform three operations on the knee, including two for osteochondritis dissecans, illustrating his technique of reattaching the loose bone and cartilage fragments with stainless-steel nails. Informal ward rounds were held, and in the late afternoon we made a quick visit to St. Andrews University. In the evening we were dinner guests of Mr. and Mrs. Smillie.

Our trip South began, and in Sheffield we were met by Mr. F. W. Holdsworth, Mr. E. A. Nicoll, and Mr. W. J. W. Sharrard.

May 24, 25, and 26

On Sunday we visited the Lodge Moor Spinal Injury Centre and were much impressed with the professional program under the direction of Dr. Alan Hardy, Mr. Holdsworth, Mr. Nicoll, and Mr. Sharrard. Dr. Hardy and Mr. Holdsworth discussed their concept of the mechanisms of injuries and the management of the various types of fracture of the spine. They use the plating procedure in the thoracic and lumbar spines only on rotary, unstable fractures which present such a problem in nursing after-care. The internal fixation serves as a means of stabilization during the early period until interbody fusion spontaneously occurs.

At the Sheffield Royal Infirmary clinical rounds were conducted by Mr. Holdsworth, Mr. Sharrard, and Mr. Nicoll. In the afternoon we visited the Children's Hospital, where Mr. Sharrard discussed some patients of his who had myelodysplasia.

After we left Sheffield we drove to Chesterfield, where we visited the Chesterfield Royal Hospital. Mr. E. A. Nicoll, our host, discussed his concept of the treatment of intracapsular fractures of the femoral neck and grafting in non-union of long bones. He made a statement to us which was in part philosophical, saying that in his estimation an operation to be really good should be one that could be carried out by an average surgeon, and should not be a technique which was good only in the hands of the most skilled surgeon. We were guests of Mr. and Mrs. Nicoll in their home and the evening was spent in a song fest in which Mr. Guy Pulvertaft, Mr. Holdsworth, and Mr. Sharrard joined.

May 27

Our trip to the Harlow Wood Orthopaedic Hospital was through famous Sherwood Forest. At the hospital several excellent clinical presentations were made, with Mr. J. P. Campbell serving as moderator. Of particular interest was Mr. H. R. Lunt's paper on bone and joint tuberculosis. In the afternoon various members of the staff also presented some interesting clinical problems. That evening we were driven to Kettering, where we were met by Mr. R. W. Butler and Mr. T. J. Fairbank, who then drove us to Cambridge. In Cambridge we stayed in the homes of Mr. Butler and Mr. Fairbank.

May 28 and 29

Our last scheduled professional visit was at Addenbrooke's Hospital in Cambridge. Mr. Butler discussed vertebral osteochondritis, and Mr. Fairbank discussed epiphyseolysis of the capital femoral epiphysis and its effect on the shape of the femoral head. Effects of accelerated growth of the animal on bone maturation were the topics presented by Dr. Widdowson and Dr. Dickerson, of the Department of Experimental Medicine. In addition, Colonel J. A. Hickman, of the School of Veterinary Medicine, presented a talk on some lesions of the

knee and the hip in the dog, which are similar to those seen in human beings. In the evening, we had dinner in the Senior Common Room at Trinity College with members of the Area Orthopaedic Consultants.

We returned to London and to the excellent accommodations in the Nuffield Surgical Institute at the Royal College of Surgeons.

May 30, 31, and June 1, 2, and 3

We attended the A.B.C. Club Dinner on Saturday evening at the R.A.F. Club. We were greatly honored by the large attendance of former Traveling Fellows, many of whom came great distances. Mr. Osmond-Clarke, President of the A.B.C. Club, was our toastmaster.

The following day we visited Hindhead, the country home of Sir Reginald Watson-Jones. After a delightful luncheon, the afternoon was spent felling trees, fishing, and relaxing.

The final three days enabled us to choose our own diversion; some of us explored the streets of London, and others preferred the Champs Elysées.

Reluctantly, we boarded the train for Southampton and embarkation. Mr. Ellis, Dr. Howkins, and Mr. Dudney again expedited our trip through Customs, and we boarded the Queen Elizabeth for the homeward voyage. The trip was enjoyable although the weather was typical of the North Atlantic during this season. We docked in New York on Monday, June 9, officially concluding our 1959 Traveling Fellowship Program.

Conclusion

The orthopaedic problems in Great Britain certainly are similar to those seen in this country, although their handling probably is more uniform because of the orthopaedic organization. The organization of regional orthopaedic centers, which are largely dominated by one institution, naturally reflects the feelings of the institution on the management of specific diseases. Throughout Great Britain we found that arthrodeses are much more commonly carried out on the major joints than they are in this country. Another contrast was the great individual experiences which many orthopaedic surgeons have had in treating particular entities. This is because of the concentration of patients in a given area where they are under the care of a small number of consultants. The number of patients seen and handled by an individual consultant is many times larger than that cared for by an orthopaedic surgeon in a comparable position in the United States and Canada.

Tuberculosis is more common in Great Britain than in this country although its incidence is falling rapidly. The anterolateral approach for the drainage of abscesses is frequently utilized in the surgical treatment of tuberculosis of the spine. The chemotherapeutical treatment in bone and joint tuberculosis varied a great deal throughout the areas visited.

Two radically different views on the early management of spinal cord injuries were presented to us, yet the end results were similar. In Great Britain the emphasis is on a spinal injury centers as an integral unit within a general medical and surgical hospital. In the field of children's orthopaedics there still is great emphasis on treatment of congenital dislocation of the hip, an entity that is seen much more frequently in Great Britain than in the United States and Canada. The staff at the Robert Jones and Agnes Hunt Orthopaedic Hospital presented several different concepts in the management of scoliosis, particularly of the infantile or childhood type. They have done a large number of epiphyseal arrests of the convex side of the curve with interbody fusion. The end results, however, are of too recent duration for clinical evaluation.

In conclusion, the Traveling Fellows wish to express their most sincere thanks to The American Orthopaedic Association and The Canadian Orthopaedic Association for sponsoring and arranging this tour. We have made many friendships which we will cherish for the remainder of our lives. On a personal basis the value of this tour to us will grow in the years to come. Although it is impossible to assimilate all the material presented to us in this relatively brief period, we are certain that exchange fellowships are tremendously important in fostering an exchange of information. The British Orthopaedic Association and all of its members were magnificent hosts and treated us with every possible courtesy and kindness. We wish to extend particular thanks to Mr. Norman Capener and Mr. John Crawford Adams for all of their efforts in preparing such an outstanding itinerary for us.

Those of us who were privileged to participate in the tour this year sincerely hope that the Traveling Fellowship Exchange Program will be continued between North America and Great Britain.

John P. Adams, M.D.
Gordon W. Cameron, M.D.
Sherman S. Coleman, M.D.
Andrew H. Crenshaw, M.D.
James S. Miles, M.D.

Proceedings

THE AMERICAN ORTHOPAEDIC ASSOCIATION

ANNUAL MEETING: LAKE PLACID CLUB, LAKE PLACID, NEW YORK
JUNE 15 THROUGH JUNE 18, 1959

Interscapular Fascial Transplants. An End-Result Study of 32 Cases. DR. J. VERNON LUCK [1] and DR. C. L. LOWMAN [2] discussed the technique devised by Lowman in 1928 of transplanting a fascia lata graft between the scapulae for scapular and upper-extremity paralysis. The majority of the forty-seven operative procedures of the series were carried out by Lowman. Thirty-two patients—nineteen male and thirteen female—were available for follow-up examination and evaluation. At the time of operation the oldest patient was thirty-four and the youngest three; the average age was 12.6 years. The length of follow-up varied from two years to twenty-nine years, with an average of 9.3 years. Poliomyelitis caused paralysis of scapular muscles in nineteen patients, brachial birth palsy in two, and progressive muscular dystrophy in one.

The clinical results were classified as good, fair, or poor. Of the thirty-two patients, twenty-three (71.9 per cent) had good results, five (15.6 per cent) had fair results, and four (12.5 per cent) had poor results.

In conclusion, the authors read that:

1. In properly selected cases, interscapular fascial transplants can result in one or more of the following benefits: increased shoulder and upper-extremity function, increased endurance, increased vital capacity, improved stability and endurance in sitting, and improved posture.

2. Properly graduated intermittent tension stresses create hypertrophy of the fascial graft.

3. Interscapular fascial grafts employed in childhood will grow parallel with the growth of the child.

4. Scapular stability is essential to proper function of the shoulders. This stability must come either from proper strength and coordination of the scapular muscles or from techniques such as interscapular fascial transplants.

5. Interscapular fascial transplants deserve wider acceptance than they have received in the past.

The paper was discussed by DR. GEORGE EATON [3] and DR. RICHARD KIENE [4], both of whom were in essential agreement with the authors' conclusions. Dr. Kiene stressed the value of attaching the transplant to a functioning muscle when possible. In closing, Dr. Lowman elaborated on several technical details of the operation.

An Estimate of Prognosis in Cerebral Palsy. DR. WILLIAM COOPER [5] stressed the importance of prognosis in determining the goals of therapy and the type of treatment indicated in cerebral palsy. After pointing out that medical literature has little to offer in this connection, the author presented his method for the estimation of a patient's outlook with respect to physical independence, social adjustment, employability, and need for domiciliary care. The method involves tabulation of clinical data according to established standards. Pertinent information is coded on sorting cards to analyze data from a large group of patients. The results of a study of 500 consecutive cases were reported; these represent the preliminary findings in a projected survey of approximately 3,000 patients.

In the discussion, DR. WINTHROP M. PHELPS [6], too, stressed the need for determining the prognosis accurately. He pointed out that mild forms of cerebral palsy are frequently unrecognized and that Dr. Cooper's statement about the need for domiciliary care was based only on patients who have sought medical care. DR. H. RELTON MCCARROLL [7] admitted the importance of being able to make an accurate prognosis but stressed that an accurate prognosis was of little value unless (1) it was accepted by the parents, and (2) the physician in charge was willing to persist with elaborate therapy in the face of a hopeless prognosis.

Effects of Rotary and Valgus Malpositions on the Blood Supply to the Femoral Head. DR. FRANK B. SMITH [8] (J. Bone and Joint Surg., **41:A:** 800-815, July 1959).

1. 1930 Wilshire Boulevard, Los Angeles 57, California.
2. 2417 South Hope Street, Los Angeles 7, California.
3. 4 East Madison Street, Baltimore 2, Maryland.
4. 4312 Nichols Parkway, Kansas City 11, Missouri.
5. 535 East 70th Street, New York 21, N. Y.
6. 3038 St. Paul Street, Baltimore 18, Maryland.
7. 3720 Washington Boulevard, St. Louis 8, Missouri.
8. 1216 S.W. Yamhill Street, Portland 5, Oregon.

Surgical Treatment of Brachial Plexus Injuries. Dr. James E. Bateman [9].

The Engineering Structure of the Epiphyseal Line. Dr. Charles O. Bechtol [10] and Dr. Leonard Marmor summarized the comparative anatomy of epiphyseal cartilage in mammals as follows. Three kinds of epiphyseal cartilage are found when a classification according to shape is attempted. The first is a transverse plate, the second is a plate convex toward the joint with a cone-shaped projection near the center projecting either way, and the third, a complicated structure with four indentations into which four projections from the metaphysis interlock. Because of compressional force the last-mentioned arrangement is extremely stable. Preliminary experiments on the breaking strength of segments of epiphyseal cartilage cut longitudinally showed that the weakest area was the cartilage and that there was a marked variation in strength in the metaphyseal bone.

Effects Produced on the Cartilaginous Epiphyseal Plate of Immature Dogs by Experimental Traumata. Dr. Crawford J. Campbell [11], Dr. Andres Grisolia [12], and Dr. George Zanconato [13] (J. Bone and Joint Surg., **41-A**: 1221-1242, Oct. 1959).

An Evaluation of Epiphyseodesis and Treatment of Leg-Length Discrepancy. Dr. Philip D. Wilson [14], Dr. T. Campbell Thompson [15], Dr. Lee Ramsay Straub [16], and Dr. Philip A. Granieri [17] presented an analysis of the results obtained by 192 patients who had had either epiphyseal arrests or stapling of the femoral or tibial epiphysis for the equalization of leg length at the Hospital for Special Surgery. Eighty-five per cent of these patients had satisfactory results. In twenty-four patients there was either varus, valgus, or recurvatum deformity. In ten patients the deformity was severe enough to require osteotomy.

The authors emphasized the technical aspects of the operation, the choice of time for arrest, and the need for further data to refine the procedure and reduce the number of complications.

In discussion, Dr. William T. Green [18] disagreed with the author's opinion that, in general, the tibial epiphysis could be arrested when the patient was ten or eleven years, and, if shortening remained, this could be supplemented by an arrest of the femur. He felt that this was an oversimplification and that chronological age alone did not provide sufficiently accurate means for the prediction of expected correction. In his opinion available tables based on sex, skeletal age, and previous growth records, together with an estimate of family characteristics and other clinical signs, give a better indication of the correct time to do an epiphyseal arrest. Dr. J. Warren White, in his discussion, stated that he preferred to rely on the simple formula of estimating the date of maturity as fourteen years in girls and as sixteen years in boys, anticipating an annual retardation of three-eighths of an inch after epiphyseodesis of the distal end of the femur and one-quarter of an inch shortening annually after arrest of the proximal tibial epiphysis. He also emphasized that most of the deformities that complicated the postoperative course of these patients were due to poor surgical technique.

The Effects of Continuous Compression on Living Articular Cartilage. Dr. R. B. Salter [19] and Mr. Paul Field [20] presented the results of an experimental investigation of the effects of continuous compression on living articular cartilage. Continuous compression of living articular cartilage in monkeys and in rabbits was produced by a clamp in some animals and by simple immobilization of the joint in a forced position in others. One hundred and thirteen compressed joints were examined; eighty-seven of these were suitable for study. Lesions varying from superficial necrosis to loss of the full thickness of articular cartilage were observed in the compressed area of articular cartilage in all of the eighty-seven joints subjected to continuous compression for six days or longer. These lesions were produced by simple immobilization of the joint in a forced position and by clamp compression, but not by immobilization alone. The extent of the lesion varied directly with the duration of continuous compression.

It was concluded that the lesion is the result of interference with the diffusion of nutritive fluid through the intercellular substance of the cartilage. The pressure necrosis of cartilage so produced is probably irreparable and may interfere with subsequent growth of the epiphysis. It may also act as the starting point in the development of degenerative arthritis.

9. 170 St. George Street, Toronto 5, Ontario, Canada.
10. University of California Medical Center, Los Angeles 24, California.
11. 721 Madison Avenue, Albany 8, New York.
12. United States Veterans Hospital, Kansas City, Kansas.
13. Pittsfield, Massachusetts.
14. 535 East 70th Street, New York 21, N. Y.
15. 535 East 70th Street, New York 21, N. Y.
16. 535 East 70th Street, New York 21, N. Y.
17. 535 East 70th Street, New York 21, N. Y.
18. 300 Longwood Avenue, Boston 15, Massachusetts.
19. Medical Arts Building, Toronto, Ontario, Canada.
20. Medical Arts Building, Toronto, Ontario, Canada.

The similarity of articular cartilage in animals to that in man and the observation of joint degeneration associated with immobilization of human joints in forced positions provide indirect evidence that the same principle may apply in man.

Clinically, however, the development of pressure necrosis of articular cartilage is difficult to detect because it is both painless and occult; its prevention, therefore, is of considerable importance. The authors noted certain clinical situations in which joint degeneration was observed in association with immobilization of a joint in a forced position, and suggested that such joint degeneration might be prevented by avoiding immobilization of joints in forced positions.

Fundamental Aspects of Muscle Function. Wilfried F. H. M. Mommaerts, Ph.D.[21] (J. Bone and Joint Surg., **41-A:** 1315-1326, Oct. 1959).

Fibrous Dysplasia: A Twenty-five Year Study with Follow-up. Dr. William H. Harris[22], Dr. Patricia H. Benedict[23], Dr. H. Robert Dudley, Jr.[24], and Dr. Roy Barry[25] said that although their study encompassed thirty-seven cases of polyostotic fibrous dysplasia and fourteen cases of monostotic fibrous dysplasia only the polyostotic form of the disease was to be considered in their presentation. The salient findings were: The onset of the disease usually occurs when the patient is under the age of thirteen years. However, it may appear with premature vaginal bleeding at the age of three months, or it may only be recognized as an asymptomatic widespread bone disease at the age of sixty-eight, when it turns up as an incidental finding. When the disease is extensive in a young child, it usually progresses, thus leading to increasing deformity and many fractures. Progression of the bone lesions occurs by extensions of preexisting lesions, by the development of new lesions, and by an increase of deformity in structurally inadequate bones. Eighty per cent of the patients sustained at least one fracture. Fifty per cent of the female patients showed precocious sexual development and several had delivered normal children. None of the children of the patients in this series have shown the disease. Three of the patients with extensive disease at an early age died, apparently as the result of their disease. In no instance, however, was there a verified case of malignant transformation from fibrous dysplasia, except in patients to whom heavy doses of irradiation had been given twenty years prior to the appearance of the sarcoma. Over 90 per cent of the patients had involvement of the femur. Histologically the lesions consist of a benign fibrous-tissue stroma with islands of membranous new-bone formation interspersed throughout. The incidence and importance of the presence of cartilage in fibrous dysplasia appear to have been overemphasized. Intramedullary fixation combined with autogenous-bone grafts is considered the most satisfactory procedure for the prevention of increasing deformity, persistent pain, and non-union, which may characterize this disease.

Dr. Joseph E. Milgram[26], in discussion, compared the findings in the series reported by the authors with those in a series of forty cases from the Hospital for Joint Diseases and said the findings in the two series were similar. Dr. Clinton L. Compere[27] commented on the histological findings in fibrous dysplasia.

Electromyographic Study of Transplanted Muscles about the Knee in Poliomyelitic Patients. Dr. David H. Sutherland[28], Dr. Frederick C. Bost, and Dr. Edwin R. Schottstaedt[29] presented an electromyographic study of twenty postpoliomyelitic patients who had had thirty-seven muscle transplantations for quadriceps insufficiency.

Electromyograms and gait movies were filmed simultaneously on the same reel. The phasic activity of each muscle studied was plotted on polar coordinate graph paper. The graphs and the graphs of five normal control patients were shown. Numerous phase conversions were evident in both transplanted and non-transplanted muscles. Extension of the phasic activity of the gluteus maximus through most of the stance phase and conversion of hamstring activity to stance phase were observed in non-transplanted muscles. Ten of fourteen hamstring transplantations achieved stance-phase activity roughly comparable to that of the quadriceps femoris. Two of eleven sartorius and four of twelve tensor transplantations achieved stance-phase activity. It was noted that the tensor and sartorius transplants frequently functioned while the hip and knee were flexing. A preliminary report was made of sartorius-tensor transplants converted to one-joint muscles by detachment proximally from the anterosuperior iliac spine with reinsertion in the region of the greater trochanter. Conclusive evidence regarding the function of these transplants is not yet available.

21. Cardiovascular Research Laboratory, University of California Medical Center, Los Angeles 24, California.
22. Massachusetts General Hospital, Boston 14, Massachusetts.
23. Massachusetts General Hospital, Boston 14, Massachusetts.
24. Massachusetts General Hospital, Boston 14, Massachusetts.
25. Massachusetts General Hospital, Boston 14, Massachusetts.
26. 1919 Madison Avenue, New York 35, N. Y.
27. 720 North Michigan Avenue, Chicago 11, Illinois.
28. 595 Buckingham Way, San Francisco 27, California.
29. 384 Post Street, San Francisco 8, California.

The Anatomy of Congenital Talipes Equinovarus (with Ten Dissected Specimens). Dr. George W. Settle [30] said that he had dissected and studied ten club feet from stillborn infants to clarify the pathological anatomy in congenital talipes equinovarus. The findings in these specimens were uniform and consisted of severe deformities of the shape of the talus, which were shown in detail by photographs and illustrations. The soft tissues all conformed to the equinovarus position of the bones, but no isolated soft-tissue deformities such as peroneal atrophy, or anomalous tendon insertions, were identified. Histological studies of the soft tissue and spinal cords in an effort to elucidate the etiology of club-foot were unrevealing. The findings in this study were consistent with those in the majority of the twenty-four previously reported dissections of infantile club-foot. The anatomical deformities of patients with club-foot were also demonstrated by arthrograms.

Correlation of the Myelogram to Clinical and Operative Findings in Lumbar-Disc Lesions. Dr. W. Edward Lansche [31] and Dr. Lee T. Ford [32] said that in the past it was the practice on the orthopaedic surgery service at Barnes Hospital not to employ the myelogram in those patients operated on for disc lesions in the lumbosacral spine since it was believed that an accurate diagnosis and localization of the lesion could be made by history and physical examination. However, starting in September 1946 myelograms were employed in a series of patients with low-back pain and in 1950 Ford and Key reported their experience with myelography in 253 patients 206 of whom had surgical exploration of the lumbosacral canal. They found positive correlation of 72.3 per cent and felt that the myelogram was a valuable aid in diagnosis, which might be a helpful factor in borderline cases. At that time they felt that a lumbar myelogram should be reserved for those cases in which the diagnosis or the location of the lesion was not sufficiently clear on clinical grounds to enable the surgeon to operate with confidence. In 1952 Ford, Ramsey, Holt, and Key reported their additional experience with 100 consecutive patients who had myelography followed by surgical exploration of the lumbosacral canal for lumbar-disc ruptures. A positive correlation of 60 per cent was found and again it was felt that myelography was not necessary if the history, clinical course, and physical findings definitely indicated a disc lesion and the surgeon was able to determine the approximate location of the abnormal disc. Since then the myelogram has been used more extensively, and in the last seven years almost every patient on the orthopaedic surgery service suspected of having a lumbar-disc lesion requiring surgical intervention has had a myelogram. A total of 866 cases, including the two series mentioned, were analyzed in an attempt to summarize our entire experience with lumbar myelography and to correlate this with the clinical and operative findings.

The technique of myelography as well as the types of myelographic defects found in the spot roentgenograms were described. In 866 cases between 1946 and 1959 there were 625 positive and thirty-seven negative myelograms confirmed at operation, an accuracy of 76.4 per cent. Major discrepancies were noted in 150 cases (17.3 per cent) and minor discrepancies in fifty-four cases (6.2 per cent). Nine neoplasms masquerading as lumbar-disc lesions were found in 866 cases, an incidence of 1 per cent. Only two of these neoplasms were definitely diagnosed before operation, despite myelography. In patients in whom operation for a lumbar-disc lesion is clearly indicated, a negative myelogram should not prevent the surgeon from exploring the lumbar spinal canal. Myelography can be a valuable aid in diagnosis and may be a very helpful factor in borderline cases. A lumbar myelogram should not be made routinely in patients suspected of having a ruptured intervertebral-disc lesion unless surgical treatment is being considered. We now believe that myelography should routinely precede surgery for lumbar-disc lesions.

Lumbosacral-Disc Disease. The Results of Surgical Treatment. Dr. Beckett Howorth [33] reviewed briefly the history of spine fusion and described his own technique for removal of a ruptured intervertebral disc and spine fusion, using, in the majority of cases, the Hibbs method combined with fixation of the articular processes by transfixion screws. He reported his results in 238 patients on whom he had performed 250 operations for low-back pain from September 1939 to January 1958. There were 136 female and 102 male patients with an age range of seventeen to seventy-one years. One hundred and eighty-one of the patients had sciatic pain, as well as low-back pain. Follow-up evaluations from one to twenty-one years after operation were available on 102 patients with disc removal and spine fusion, thirty-four with inspection of the disc and spine fusion, forty-four with fusion alone, twenty-six with fusion for spondylolisthesis, six with removal of the disc alone, and seven with extension of an existing fusion. Follow-up roentgenograms of the 180 primary fusions (excluding spondylolisthesis) showed one proved pseudarthrosis and three doubtful fusions at the fourth to fifth lumbar level. Among the twenty-six fusions for spondylolisthesis there were four failures, three of which were successfully repaired by a second operation. Eighty-seven fusions con-

30. 3820 Greenspring Avenue, Baltimore 11, Maryland.
31. 41 North Central, Clayton 5, Missouri.
32. 52 Maryland Plaza, St. Louis, Missouri.
33. 1 Atlantic Street, Stamford, Connecticut.

fined to the lumbosacral joint were evaluated. All fused, but in six the fusion was extended in a subsequent operation to include the fourth lumbar vertebra. All the failures occurred in fusions that extended from the fourth lumbar vertebra to the sacrum.

The clinical results were considered excellent or good in 97 per cent of the spine fusions (excluding spondylolisthesis) with and without removal of the nucleus pulposus and in 95 per cent of all the fusions (including spondylolisthesis). Thirty of the patients having spine fusion were compensation cases. In addition to the fusion, the nucleus pulposus was removed in nineteen of these patients. All but two had excellent or good results and were able to return to their former work which, in most cases, was heavy labor.

Dr. Howorth concluded that careful selection of cases, removal of the nucleus pulposus when indicated, spine fusion by the technique described, and careful follow-up give excellent results.

The Role of Soft Tissues in Osteogenesis. An Experimental Study of Canine Spine Fusions. Dr. Lloyd A. Hurley[34], Dr. Frank E. Stinchfield[35], Dr. C. Andrew L. Bassett[36], and Commander Frank H. Lyon[37] (J. Bone and Joint Surg., **41-A:** 1243-1254, Oct. 1959).

Postirradiation Fractures of the Femoral Neck. Dr. William H. Bickel[38], Dr. Donald S. Childs, Jr.[39], and Dr. Charles A. Porretta[40] presented a study of nineteen patients with twenty-four fractures (five bilateral) of the femoral neck secondary to radiation therapy treated at the Mayo Clinic from 1941 to 1956 and followed for from ten months to fourteen years. In fourteen of the nineteen patients, radiation had been given for carcinoma of the female genital tract. (The average age of these patients was sixty-three years.) The majority of the fractures occurred within five years of the initial radiation therapy; one occurred twelve years after therapy. The total dosage and technique of therapy varied markedly. Pain was the first sign of impending fracture. There was no history of significant trauma in the series. Symptoms usually developed gradually but the onset was acute in a few instances. Roentgenograms at the onset of symptoms in many cases were negative.

Of these twenty-four fractures two had no treatment, and eleven patients merely used crutches, yet all the fractures united—eight with excellent, four with good results, and one with a fair result. Seven fractures were treated with metallic internal fixation and all united with two excellent and four good results and one poor result. Of the four remaining fractures one was treated with a fibular graft with an excellent result, one with a Whitman reconstruction using a Vitallium cup because of a small head fragment and irrevocable non-union, and two with Moore prostheses because of marked displacement of the fractures five and six months after onset. The result after the Whitman reconstruction was poor because of infection. The results with the Moore prostheses were good. The authors concluded that in these two patients union and satisfactory function might have followed reduction and internal fixation or bone-grafting. In one patient whose fracture healed without treatment while the patient continued to walk, roentgenograms one year after fracture suggested avascular necrosis of the femoral head, but the symptoms were not severe enough to justify treatment. The authors stressed the importance of differentiating these fractures from pathological fractures through tumor metastases and pointed out that it would appear that union of these fractures in some instances can be anticipated in about the normal time, even when the fracture is recognized late and the head has slipped into varus position, if nothing more than crutch-walking is instituted as therapy.

AMERICAN MEDICAL ASSOCIATION
SECTION ON ORTHOPAEDIC SURGERY

As Prepared by Robert J. Joplin, M.D., Secretary, Section on Orthopaedic Surgery

The 1959 Annual Meeting of the Section on Orthopaedic Surgery of the American Medical Association was held in Atlantic City, New Jersey, June 10 through June 12, 1959, under the chairmanship of Lenox D. Baker, M.D., Durham, North Carolina. A brief review of the sessions and a résumé of each paper presented follows:

The meeting on June 10 opened at 9 A.M. at the Shelburne Hotel. The following papers were presented and discussed:

34. Columbia-Presbyterian Medical Center, 622 West 168th Street, New York 32, N. Y.
35. Columbia-Presbyterian Medical Center, 622 West 168th Street, New York 32, N. Y.
36. 15-219 VC-P&S, 630 West 168th Street, New York 32, N. Y.
37. Dental Division, Naval Medical Research Institute, Bethesda, Maryland.
38. 200 First Street, S.W., Rochester, Minnesota.
39. 200 First Street, S.W., Rochester, Minnesota.
40. Mayo Foundation, Rochester, Minnesota

Complications Following Bryant's Traction. Dr. Ralph T. Lidge[1] gave a critical analysis of thirteen consecutive patients treated with overhead traction for fracture of the femur. All except one patient had received initial care. Dr. Lidge said that although confusion still exists as to how old a patient should be when Bryant's traction is used, he believes the overhead traction should be limited to those children not more than four years of age and weighing less than thirty-five to forty pounds. For the older child his treatment consisted in the initial application of a plaster spica cast or Russell balanced traction, or floating traction with a floating splint, with skin or skeletal traction.

A false sense of security has led many to feel that Bryant's traction is a simple method, but its complications are still not well known. Most of the complications observed in this series occurred during the first forty-eight to seventy-two hours after institution of treatment. The complications ranged from simple skin irritations to gangrene leading to amputation.

Dr. Lidge illustrated the complications that followed Bryant's traction by presenting the case histories of nine patients so involved. He concluded by stating that although prevention is the best form of treatment, Bryant's traction is still a common method of treatment and its apparent simplicity should not lull the doctor into a false sense of security.

The Treatment of Calcaneonavicular Bar. Dr. James I. Kendrick[2] discussed the diagnosis and the results obtained in the treatment of calcaneonavicular bar. Early diagnosis and resection of the bar before the bar becomes complete have resulted in satisfactory relief of symptoms. In the patients in whom the bar has become complete, resection of the bar is less effective and often not even effective in relieving symptoms; there has been a marked tendency for the bar to re-form. Dr. Kendrick also presented and discussed pathological specimens.

Olecranon Fractures. Dr. Scott Adler[3], Dr. Gardner Fay, and Dr. William R. MacAusland, Jr., reviewed 100 solitary fractures of the olecranon with particular regard to the end result of those treated by open reduction at the Massachusetts General Hospital.

The solitary fracture, without displacement, is best treated with plaster immobilization. The solitary fractures that had been separated had been treated with either screws or wire fixation and, although some were reported to have distractions of the fragments and loss of fixation, the separations were due, for the most part, to the faulty technique of insertion and breakage of internal fixation.

The comminuted fractures were treated with excision and suture of the triceps tendon, and these, by-and-large, had the most satisfactory end results in the entire group.

Extradural Osseous Lesions Simulating the Disc Syndrome. Dr. Harry R. Walker[4] presented seven cases of extradural osseous lesions simulating the disc syndrome, with the following diagnoses: (1) neurofibroma of the sacrum, (2) multiple myeloma of the lumbosacral spine and pelvis, (3) reticulum-cell sarcoma of the ilium, (4) chondrosarcoma of the acetabulum, (5) chondrosarcoma of the neck of the femur, (6) giant-cell tumor of the fifth lumbar vertebra, and (7) Ewing's tumor of the sacro-iliac joint.

Four of the patients had one or more laminectomies for a disc protrusion, but showed no improvement. Dr. Walker stressed the need for a thorough clinical and roentgenographic examination of the osseous skeleton, particularly the lumbar and pelvic areas, before proceeding with elective disc surgery.

Management of Musculo-Skeletal Lesions in the Hemophiliac Child. Dr. Donald M. Qualls[5], Dr. Irving J. Wolman, and Dr. Jesse T. Nicholson presented a year's experience with 100 children with hemophilia. Musculoskeletal deformities were minimized by (1) early recognition, application of compression bandage, splinting beyond neighboring joints, elevation of the extremity, and sedation; (2) correction of clotting time with frozen, fresh plasma or whole blood; (3) repeated aspirations of involved joints, flushing with hyaluronidase, intra-articular instillation of steroids (hydrocortisone), and, in selected cases, systemic administration of corticoids; (4) graduated exercise beginning in balanced suspension; and (5) vocational training in physical activities. In late cases with joint contractures, Buck's traction and wedging casts were helpful in correction of deformities. Follow-up bracing is essential to prevent recurrence.

Hip Shelf Operation in the Adult. Dr. David M. Bosworth[6], Dr. J. William Fielding, Dr. Tadao Ishizuka, and Dr. Ridvan Ege reported the results obtained by thirty-three adults who had a hip-shelf operation; the average follow-up was eight years. Operation consisted in implanting a large long hip shelf taken from the outer surface of the ilium and placed

1. 4833 West Peterson, Chicago 46, Illinois.
2. 2020 East 93rd Street, Cleveland 6, Ohio.
3. Children's Medical Center, Boston 15, Massachusetts.
4. 485 34th Street, Oakland 9, California.
5. 1740 Bainbridge Street, Philadelphia 46, Pennsylvania.
6. 742 Park Avenue, New York 21, N. Y.

beneath the gluteal muscles and snapped into a slot cut in the outer ilium. The hip-shelf procedure was used mainly for congenital dislocation and congenital subluxation, but was also used on occasion for dislocation after poliomyelitis and for coxa magna with osteo-arthritis. The benefits achieved were: re-establishment of stability, enlargement of the area of the weight-bearing surface, increased power of action of the gluteal muscles, and denervation of the capsule beneath the shelf. There was marked improvement in stability of the hips in all patients and relief from pain, limp, and discomfort in almost all.

Non-union of the Clavicle. Dr. Charles S. Neer II[7] presented a study made of eighteen ununited fractures in adult patients. The four outer-third lesions were, without exception, associated with disruption of the coracoclavicular ligaments. The most important causal factor in mid-clavicular non-union, however, was improper open treatment initially. The original therapy had been open operation in ten of the fourteen ununited middle-third fractures. Symptomatology usually required treatment. Two pathological conditions were recognized: pseudarthrosis and bone resorption. Bone repair was generally preferable to excision. Bone union was more apt to occur if, rather than bridging gaps with bone grafts, end-to-end contact was maintained.

Certain pseudarthroses of the clavicle in children, which were not included in the study, were apparently ununited fractures sustained at birth, rather than congenital defects.

The Second Session of the Section on Orthopaedic Surgery of the American Medical Association was opened on Thursday, June 11, at 9 A.M. at the Shelburne Hotel. The first order of business was the election of officers. The following slate was presented by the Nominating Committee and unanimously elected:

Chairman of Section: H. Herman Young, M.D., Rochester, Minnesota;
Vice-Chairman: J. Vernon Luck, M.D., Los Angeles, California;
Secretary: Robert J. Joplin, M.D., Brookline, Massachusetts;
Delegate: Edward L. Compere, M.D., Chicago, Illinois;
Alternate Delegate: Harry R. Walker, M.D., Oakland, California;
Representative to Scientific Exhibit: James J. Kendrick, M.D., Cleveland, Ohio;
Assistant Representative to Scientific Exhibit: E. Burke Evans, M.D., Galveston, Texas;
Representatives to American Board of Orthopaedic Surgery: David S. Grice, M.D., Philadelphia, Pennsylvania, and Edwin R. Schottstaedt, M.D., San Francisco, California.

After the Business Session the following papers were presented:

Observations on the Long-Term End Results of Ninety Cases of Calvé-Legg-Perthes Disease. Dr. Earnest B. Carpenter[8] and Dr. Douglas O. Powell discussed their conclusions and observations after a study of ninety cases of Perthes disease. End-result roentgenograms, up to as long as twenty-five years after completion of treatment, were used as the basis of this study and for the conclusions reached. No attempt was made to compare the end result of one type of treatment with another since the authors were aware that controversy exists as to how best to treat Perthes disease. The cases were divided into three groups, depending on the amount of destruction of the capital femoral epiphysis at the time of admission: Group I, minimum changes; Group II, moderate changes; and Group III, extensive changes. There were seventy-six boys and fourteen girls, a ratio of five to one. Fifty-four per cent of the patients were over the age of seven at the time of admission. Only thirty were in Group I, which suggests that all practitioners must be impressed with the need for a high index of suspicion of Perthes disease, thus permitting earlier diagnosis and treatment before the changes in the femoral head are irreversible. All patients in Group I had an excellent end result. All patients in Group III had a poor end result, regardless of the method of treatment. All patients below the age of five had an excellent end result, and all patients over the age of eight had a poor end result. Restriction of weight-bearing during the period of epiphyseal destruction is necessary if an essentially normal-appearing femoral head is to be the desired end result. The ischial weight-bearing brace was not an effective means of preventing weight-bearing in this group of cases. The authors stressed the importance of early diagnosis and restriction of weight-bearing to provide a good end result and prevent irreversible changes in the femoral head.

Chairman's Address. Dr. Lenox D. Baker[9].

Discography: Technique and Interpretation. Dr. Charles Keck[10] presented a technique of intervertebral-disc puncture which may be used as a guide and adjunct to myelography in evaluating low-back pain. The method was described in detail and illustrated diagrammatically. The advantages of discography over myelography are greater accuracy and additional information. Sample discogram patterns were illustrated to facilitate roentgenographic interpretation.

7. 180 Fort Washington Avenue, New York 32, N. Y.
8. 116 East Franklin Street, Richmond 19, Virginia.
9. Duke University Hospital, Durham, North Carolina.
10. Duke University Hospital, Durham, North Carolina.

Interpretation depends on the correlation of five factors: (1) the amount of dye accepted by the intervertebral space; (2) the degree of pressure necessary to inject the contrast material; (3) reproduction of the patient's pain on injection; (4) roentgenographic pattern of dye dispersion; and (5) correlation with the clinical picture.

Dr. Keck also discussed the advantage of injecting hydrocortisone in conjunction with diodrast into the disc space.

The Diagnosis and Treatment of Osteoporosis. Dr. James A. Nicholas[11] and Dr. Philip D. Wilson reported on the clinical characteristics and follow-up studies of diagnosis and treatment of fifty-five patients with osteoporosis with compressed vertebrae admitted to The Hospital for Special Surgery between 1950 and 1958.

The findings revealed that ten of fifty-five patients were not improved despite various forms of treatment, including hormones. Of thirty-seven patients receiving hormones, nineteen were able to continue them for long periods of time and eighteen required discontinuation because of serious side effects.

The authors concluded that osteoporosis sometimes is a progressive, disabling disease in which estrogen-androgens are not always effective. Nevertheless, an attempt should be made to use hormones for those patients who must be readmitted to the hospital frequently; they sometimes seem to respond dramatically to this form of therapy.

Congenital Dislocation of the Hip in the Early Walking Group. Dr. Edward A. Nalebuff[12] and Dr. Paul L. Norton reviewed the results of treatment of congenital dislocation of the hip in the early-walking group (from one to three years) at the Lakeville State Sanatorium from 1949 to the present time.

The authors said that abduction-internal rotation is the preferred position of immobilization after closed reduction, and that the correction of excessive anteversion by rotation osteotomy is often necessary to maintain a stable reduction.

The use of the frog-leg position for prolonged periods was often followed by redislocation, which was then satisfactorily managed by converting to abduction-internal rotation or to open reduction, with or without rotation osteotomy.

Ostamer—A Polyurethane Polymer: Its Use in Fractured and Diseased Bones. Report of Thirty-five Cases. Dr. Michael P. Mandarino[13] and Dr. Joseph E. Salvatore discussed their use of ostamer and the results obtained in thirty-five patients.

Ostamer is a rigid polyurethane foam, it can be poured in liquid form, and has properties of strength, osteogenesis, non-toxicity, cohesiveness, and ease of handling at surgery. It is the most extensively studied plastic used in the human body to date. Experiments have been progressing for four years to ascertain the toxicology, absorption, metabolic route of excretion, osteogenetic properties, carcinogenicity, and strength-potential of the substance. It can now be stated that ostamer has the strength per square inch and the adhesiveness necessary for bone fixation, and that it provides a chemical lacunar system. New bone not only climbs along the surface, but grows through the plastic, as would be expected with an autogenous graft. This permits earlier ambulation of the patient and a more rapid return to a physiological norm than other forms of treatment.

As of June 1, 1959, 220 patients have been treated by ostamer and reported; 93 per cent have had successful results.

The authors concluded that of the thirty-five patients personally treated by them, twenty-four had had previous surgery and eighteen of these had previous infection. In the total group of thirty-five patients with fractured or diseased bones, twenty-eight showed successful and uneventful healing; five continued to have drainage (but roentgenograms show bone proliferation); and two, with involvement of the tibia, had results classified as failures. All infections occurred in the tibia.

The possibilities of successful results in difficult procedures have been so enhanced by the use of ostamer that one finds it difficult not to be stimulated. The use of ostamer in bone cysts, pre-amputation, and in pathological fractures associated with terminal malignant growth is certainly advised.

The Third Session of the Section on Orthopaedic Surgery of the American Medical Association was a Combined Meeting with the Sections on Physical Medicine and General Practice. The Combined Meeting, which opened on Friday, June 12, at 9:00 A.M. at Convention Hall, was a Symposium on Athletic Injuries, Dr. Don H. O'Donoghue of Oklahoma City, Oklahoma, *Moderator*.

Moderator's Address. Dr. Don H. O'Donoghue[14] said that most physical education of

11. 110 East 87th Street, New York 28, N. Y.
12. Veterans Administration Hospital, Jamaica Plain 30, Massachusetts.
13. 210 North 15th Street, Philadelphia 2, Pennsylvania.
14. Lee at 10th Street, Oklahoma City 3, Oklahoma.

our youth of the United States is carried out through organized athletics. There are tremendous advantages to competitive athletics if they are conducted on a proper basis. Athletics improve the mind, body, and spirit. The principal disadvantage is that there are too many injuries. The previous lack of rapport between doctors and athletes is rapidly reversing itself through improved understanding of the common interest of the parents, player, physician, trainer, and coach in the prevention of athletic injuries, as well as treatment and rehabilitation.

The major concepts of treatment of athletic injuries are: (1) the goal must be 100 per cent recovery; (2) adopt the best method of treatment, not the easiest; (3) do not permit outside pressure to influence the selection of treatment; (4) the doctor must believe in competitive athletics; and (5) above all, treatment must be prompt.

Report of Activity of the American Medical Association Committee on Injuries in Sports. Dr. Allan J. Ryan[15] said that the establishment of a Committee on Injuries in Sports by the American Medical Association in December 1953 was the beginning of an organized approach to medical problems in athletics in this country. Through its contacts with the National Collegiate Athletic Association, the National Association of Intercollegiate Athletics, and the National Federation of State High School Athletic Associations, the Committee has established close cooperation with those engaged in the training and care of athletes at the college and high-school level. It has promulgated, in connection with these organizations, a set of standards for the protection and care of college and high-school athletes. It has stimulated the organization of regional, state, and local conferences on the prevention and treatment of athletic injuries. Members of the Committee have appeared as speakers on the programs of national organizations concerned with the inter-relationship between health and athletics. Special recommendations relating to the participation of students at the junior high-school level in football contests and on making weight for wrestling and boxing events have been made by the Committee. Further developments in the care and protection of athletes depend on the future interest and participation of physicians in organized programs relating to athletics.

Athletic Injuries at the High School Level. Dr. Andrew Tomb[16] said that any physician called on to render aid to an injured athlete is on exhibit before a crowd more than at any other time in his professional career. On the field he must often make a diagnosis in a matter of moments, whereas in his office he would take much more time in addition to making roentgenograms. If he allows a temporarily confused boy to stay in the game and then on the next play this child is hurt, the physician is blamed. The weak points in high-school contact sports are ill-fitting equipment and poor direction in the proper use of protective equipment.

Athletic Training. Mr. Kenneth Rawlinson[17] stated that an athletic trainer's duties are varied, but can be placed in three categories:

1. Prevention of Injuries: More time is spent on prevention of injuries than is commonly believed. Some preventive measures are: thorough physical examinations, good practice field, physical and mental conditioning, good equipment, special protective equipment, and protective taping.

2. Treatment of Injuries: A minor and actually a less important part of our job. The trainer is the coordinator between the coaches and the physician.

3. Rehabilitation of Injuries: Again, the trainer works with the team physician.

Myositis ossificans of the humerus and pathological conditions involving the knee, shoulder, or ankle often turn up at college, although they could have been taken care of when the athlete was at high school. The physician should be fair to the athlete; if surgery is needed when the boy is at high school, recommend it—don't wait until he gets to college. Early rehabilitation or early surgery and rehabilitation was urged.

Mr. Rawlinson concluded his talk by thanking the medical profession, on behalf of athletic trainers, for their help and cooperation.

The Therapeutic Employment of Brief Maximal Isotonic Exercises. Dr. Donald L. Rose[18] said that muscle weakness, as seen clinically, is frequently caused by non-organic, neurogenic factors. Among these may be pain, apprehension, stiffness, lack of motivation, improper loading of the muscle, and improper repetition. A technique for loading of the quadriceps femoris is to increase the neurological capacity of the movement pattern, which results in increase in strength and function. The technique is rapid, effective within the limits of its applicability, and appears to be safe in clinical use.

15. 26 Fair Street, Wallingford, Connecticut.
16. 3808 North Navarro Street, Victoria, Texas.
17. University of Oklahoma, Norman, Oklahoma.
18. University of Kansas School of Medicine, Kansas City 12, Kansas.

Prevention of Athletic Injuries: Basic Considerations. Dr. Robert G. Brashear[19] listed three needs for the prevention of athletic injuries: (1) a head coach with superior qualifications; (2) an athletic-team physician who will act as consultant and participant in the athletic program; and (3) full-time lay trainer with special training in prevention and care of athletic injuries.

The National Athletic Trainers' Association has developed facilities for the education of athletic trainers, and the American Medical Association is taking this organization under its wing to assist in its all-out effort to provide trainers for all our high schools.

The Baseball Shoulder. Dr. Rex L. Diveley[20] and Dr. Paul W. Meyer said that the extreme overexertion of throwing a baseball often causes certain pathological changes in the shoulder or elbow, or both, in professional baseball players. This continued super effort causes an irritation or partial rupture, or both, of the origin of the triceps brachii on the infraglenoid tuberosity of the scapula. This often causes a calcific deposit or an irritation at the point of muscle origin.

In patients with a sore or painful elbow, the point tenderness will be localized over the tip of the olecranon or over the internal or external condyle of the humerus. This results in irritation, calcific deposit, or osteophytic formation.

These painful shoulders and elbows have been successfully treated with long-lasting hydrocortone, and the calcific deposit has often been absorbed.

Shoulder Girdle Injuries. Dr. Carl E. Badgley[21] discussed the following injuries sustained by athletes:

1. Neurogenic: traction injuries to the plexus, intervertebral-disc factors, posterior or lateral cord injuries, peripheral nerve injuries, and scalenus syndrome (cervical rib).
2. Arthrogenic: acromioclavicular displacement, sternoclavicular displacement, dislocation of the shoulder, and dislocation of the cervical spine.
3. Fractures: clavicle, humerus, coracoid, and acromium.
4. Soft-tissue injuries: musculotendinous-cuff tears, biceps long head tear, pectoralis major tear, and peritendinitis of the biceps tendon.

Knee Injuries Incurred in Sport. Dr. T. B. Quigley[22] said that most of the trick knees of middle age dated from school or college injuries and could be avoided by common sense preventive measures, prompt diagnosis, and appropriate treatment. The most important factors in prevention are physical fitness, good coaching, and thorough pre-participation physical examination. Diagnosis depends on careful, thorough examination as soon as possible after injury. Roentgenograms are almost always necessary. Advantage should be taken of the analgesia imposed by injury to determine the integrity of ligaments by diagnostic manipulation.

The five most common injuries are: contusion, sprain, meniscus injury, ligament rupture, and fracture or epiphyseal displacement. Contusions and sprains are treated by cold, compression, rest, and elevation for twenty-four to forty-eight hours, then heat and graduated exercise. Most meniscal injuries are accompanied by ligament sprain which should be allowed to heal before surgery is recommended. Ruptured ligaments should always be repaired surgically. Bone injuries are treated as indicated. Fractures should be openly reduced whenever necessary; epiphyseal injuries almost never.

Rehabilitation of Athletes with Patellar Injuries. Dr. Donald R. Lannin[23] kept records on primary patellar injuries and on the incidence of associated patellar injuries with other knee injuries over the past ten years. Thirty-five per cent of meniscal and ligamentous knee injuries in athletes show an associated injury or irregularity of the posterior aspect of the patella. The presence of this patellar irregularity changes the entire program of rehabilitation of the knee after surgery; it is a major factor in the prognosis for recovery and return to athletics.

Protective Equipment and Protective Taping. Mr. Kenneth B. Rawlinson[17] discussed the types, costs, and styles of equipment worn in collegiate and high-school football, and demonstrated the following types of preventive taping used at the University of Oklahoma:

1. Ankle: figure-eight ankle wrap; Louisiana ankle wrap (best); basket-weave with Oklahoma heel lift (with or without the felt "U").
2. Longitudinal arch strapping.
3. Foot rest strapping.
4. Knee: methods of supporting medial, lateral, or cruciate ligament strains, and knees that have been operated on.

19. 807 Medical Arts Building, Knoxville, Tennessee.
20. 4312 J. C. Nichols Parkway, Kansas City 11, Kansas.
21. 1313 East Ann Street, Ann Arbor, Michigan.
22. 319 Longwood Avenue, Boston 15, Massachusetts.
23. 942 Lowry Medical Arts Building, St. Paul 2, Minnesota.

ARTHUR STEINDLER

1878–1959

A great man and a beloved colleague passed away on July 21, 1959, at his home in Iowa City.

He was born on June 22, 1878, into a Viennese family already distinguished for a tradition of learning. Thoroughly grounded in the rigorous classical education of a nineteenth-century European capitol, he proceeded to make study his work, hobby, and life. In 1902 he received his degree in medicine at the University of Vienna and in that year he said he was motivated to specialize in orthopaedics. He spent the next five postgraduate years with his teacher, Edward Albert, who is best known for having devised the method for fusion of the shoulder in 1895. However, it was in America that Arthur Steindler wished to work, and in 1907 he went to Chicago as assistant to John Ridlon. Since Iowa, near by, had but two orthopaedists, he moved to Des Moines three years later and became Professor of Orthopaedic Surgery at Drake Medical School.

By 1915 he was called to the State University of Iowa in Iowa City by the far-sighted head of the Department of Surgery, Charles Rowen. Rowen insisted that if orthopaedics was ever to grow it must be a separate department from general surgery.

For thirty-five years Arthur Steindler occupied the Chair of Orthopaedic Surgery at the State University of Iowa. In 1949, retiring from active professorship to emeritus professorship, he continued his private practice in Iowa City.

Few persons who visited or worked in Iowa City will ever forget the modest, tireless man who wrote in his library from dawn to breakfast, who operated at 8:00 A.M., who probably had the heaviest teaching schedule in the land, who treated many private patients, and then turned to his evening of work for six days a week and until Sunday morning at ten as a routine.

His gracious and hospitable wife, Louise, was a nurse at the Children's Hospital at the time of their marriage in 1914. Her devotion enabled her to step aside through an entire lifetime to preserve her husband's working hours, for time was irreplaceable.

He appeared a tall, burly, gently smiling man, who often shuffled a bit as he walked. His wit was immense but ever kindly. His command of English was astonishing. He spoke seven languages fluently, and was a one-man literature-abstract system. Up to his last years he enjoyed the piano.

His attitude toward his residents was unusual, for orthopaedics filtered through his personality. He would listen attentively to the queries or comments of his youngest resident, prepared to modify or reconsider his own plan. Never did he criticize.

No resident ever blundered without Dr. Steindler's claiming the error for himself—had he been wise enough to anticipate and diligent enough to teach, the mistake would have been avoided. His humility was such that he meant it.

He genuinely respected all colleagues. In the many years that he practiced, often turbulent with activity, his staff never heard him criticize a fellow orthopaedist. There were, he said, probably good reasons for the conflicting advice if he but knew them.

His own contributions and operations were not dear to him simply because they were his own. He encouraged his staff to modify them, and in detailed analyses sought the causes for operative failure. He was progressive and open minded to the last.

His pupils were like sons to him, and he cherished them and remained loyal to each.

Personal responsibility, compassion, and a vigorous intelligence marked him as a physician. He emphasized the whole-patient concept and organized a teaching program in the University toward this end. No physician to my knowledge was ever more loved and trusted by a myriad of patients.

His scientific contributions were astonishing. He wrote 240 papers and eleven books on orthopaedic surgery. His interests were broad and varied. With his gentle but firm prodding, the Iowa legislature pioneered in the field of complete public programs for the crippled indigent. In a program for graduate education he taught over 250 orthopaedists, many of whom have built schools and centers for teaching here and abroad.

His major interests were always in challenging fields where orthopaedics was least developed—spastic paralysis, arthritis, scoliosis, neuromuscular degeneration, and poliomyelitis—and were avidly studied and marked by his industry and wisdom.

Over three decades ago he commenced to stress the need for basic research in orthopaedics, which he reiterated in his 1933 Presidential Address to The American Orthopaedic Association. To adequately equip himself for study in human mechanics he had taken courses in mathematics, physics, and engineering. Being a linguist, he brought into the English language orthopaedic material from many foreign sources, pursuing his work nightly for years in the face of exceptional demands on his time. Beginning in the twenties, when he published a paper on action current, his emphasis on biomechanical research was continuous. In 1935, when his *Mechanics of Normal and Pathological Locomotion in Man* appeared and aroused but little interest, he promptly sat down to write a better book, blaming himself in his next book's preface. He lived to see the interest shown by himself and his friends

Schwartz, Abbott, and Inman expand into the organization of the Orthopaedic Research Society in 1955, which delighted him.

Although he never thought of himself as an operative technician, he wrote one of the first monographs on upper-extremity reconstruction. For poliomyelitis he introduced Albert's arthrodesis of the shoulder, devised the extraordinarily valuable operation of flexorplasty of the elbow, and developed a good opponens-paralysis plasty which was ultimately improved and replaced by his friend Bunnell.

For lower-extremity reconstruction, through numerous early articles and later books, he presented and delineated many operations in wide use today: pantalar ankle fusion, synovectomy of the knee, and selective nerve and fascial resections.

He was the recipient of honorary degrees and professorships and enjoyed membership in British, German, Belgian, Argentinian, Mexican, Portuguese, and many other associations and societies. He was, however, most pleased with two honors: the Presidency of The American Orthopaedic Association and Honorary Fellowship in the Royal College of Surgeons.

In April 1959, with but a few months to live because of cancer, he heard that a colleague had suggested that it would be long before others like him and his great friends would again come our way. His immediate reply was, "No, no, the young men of today are wonderful. Much better than we ever were."

He managed to correct proof on his last book, which was on pain in orthopaedics, and he completed it only a few days before he died.

His personality touched many persons and imperceptibly changed them.

J. E. M.

Dr. Arthur Steindler was reared in the refined culture of the late nineteenth-century and early twentieth-century Austro-Hungarian Empire. His mother died in the United States at the age of eighty-six years and is still remembered in Iowa City for her great interest in education. She attended classes in Romance languages at the University of Iowa until shortly before her death. Her four children (two sons and two daughters) had brilliant professional careers.

When Dr. Steindler went to Chicago, in addition to a good background in orthopaedic surgery, he possessed a broad cultural background in the humanities. In his early youth he had aspired to be a professional musician, but, on the advice of his father, he entered medical school at the University of Vienna. Reading good books on literature and history and playing the piano were his hobbies. After three years in Chicago and four in Des Moines, he went to Iowa City to develop the Department of Orthopaedic Surgery of the State University of Iowa. Within a growing university in this small Midwestern town, he found a congenial intellectual atmosphere. He built his home on a bluff overlooking the Iowa River, and on the pediment of his door inscribed Horace's quotation, *"Ille terrarum mihi praeter omnis angulus ridet"*. Dr. Steindler finally found the corner of the earth that smiled to him over all others and there spent the rest of his very productive life.

He was blessed with a strong body and an inexhaustible amount of energy. After intensively working and teaching at Children's Hospital all day and reading and writing in the evenings in his home library, he found solace in playing the piano and then always read again in bed before going to sleep.

He had a refined taste in literature. He enjoyed reading Virgil, Horace, and Lucretius in Latin. He was well acquainted with classical and modern German, French, Spanish, and Italian literature. On the calm, early June evening of my first day in Iowa City, in 1941, I visited his home. He was reading in his garden, which was handsomely landscaped by Mrs. Steindler. He greeted me with his charming smile and read aloud with great delight some stanzas of "El Alcade de Zalamea" with good Castilian pronunciation. Owing to his retentive mind, it was easy for him to recite full pages of this and other works of Calderón de la Barca, Lope de Vega, Cervantes, and Gracián. He was fond also of reciting Cyrano de Bergerac in French. Of the modern Spanish writers he enjoyed Pío Baroja and José Camilo Cela. He was constantly reading Ibsen and Tolstoy. During his convalescence in the hospital following his gall-bladder operation in 1953 he read Suetonius's *The Twelve Caesars* and on our visits he would recount, with twinkling eyes, some of the gossipy stories of one of the Caesars. He belonged to two dinner clubs where he enjoyed discussions on literature, history, and philosophy. He had many friends on the campus and the veneration of all the State of Iowa.

Dr. Steindler's mother and brother were visiting relatives in Vienna in 1914 when World War I started. Throughout the duration of that war, his sensitive soul found comfort in music. He was an excellent pianist and often played duets with Professor Clapp, who was head of the Department of Music of the University and one of the outstanding American musicians of our time. He was also fond of playing Beethoven's sonatas with Dr. Byfield, who was the head of the Department of Pediatrics and a good violinist. Besides Beethoven, Mozart, Schubert, and Grieg were his favorite composers. Unfortunately, he found little time for music when he embarked on the study of kinesiology in the late twenties

and played little during his last ten years. He was too absorbed in the writing of his many books which enriched so handsomely our knowledge of orthopaedic surgery.

Dr. Steindler's only physical exercise was a brisk daily two-mile walk to watch the train roaring through the beautiful Iowa countryside at five o'clock in the morning. He found his pleasures in his work and the enrichment of his gifted mind. In orthopaedic surgery he adhered to sound biological principles and was continually occupied in slowing down the whims of passing fashionable ideas. Only well grounded and tested operations were used on the patients under his care. He was conservative but always on the lookout for new sound ideas.

In his passing, we lost not only a great teacher who enriched almost every phase of orthopaedic surgery, but also a most kind and unswerving friend.

I. V. P.

Arthur Steindler was one of the Olympian figures of modern orthopaedic surgery:

As a Thinker

He was honest and had a complete independence of mind. He was able to pursue with untiring tenacity the most complex problems of our science.

As a Writer

He not only led us through brilliant new paths in surgery, but also helped through his lucid style, to disseminate and clarify many of the basic principles of orthopaedic surgery.

As a Teacher

He was always inspiring. Because of his prodigious wealth of learning and a fabulous memory, he could bring to bear upon many clinical problems the most pertinent and unexpected facts. His mastery of many languages extended his fame beyond the English speaking world.

As a Man

He had a charming, gentle simplicity and, above all, an essential personal goodness.

This combination of scientific thought plus a warm love of humanity made him the genius that he was.

Every one of us who studied under him can truly say "With him a part of me has passed away."

R. S.-H.

Arthur Steindler as a man, and Arthur Steindler as a friend of Latin America, had facets not well known by many of his North American friends and former students. I think that he taught our specialty to more Latin Americans than anyone else. All of his former pupils feel and lament his death. His knowledge, his broadmindedness, his clinical accuracy, his deep mind, and his humbleness made the Latin American doctors call him not "Professor" but "Maestro", thus showing their veneration of the man as well as their respect for his broad knowledge and his technical and teaching ability. "Maestro" means not only the man who teaches, but the man whose every act in his own life is a vivid example, without ostentation. A master of the Spanish language, he was of great help to the Spanish-speaking students who felt lost during their first times in the United States. His mind and his way of thinking were, in great part, European. This established another link with Latin Americans because our studies followed the French pattern and we were taught to reason in the same way; thus, we sometimes understood him better than the North Americans, who thought Dr. Steindler was difficult to understand although his scientific explanations in English were clear, exact, and concise. His knowledge of eight languages enabled him to read original books and papers and to discuss and learn many things from men of other cultures, languages, and countries without resorting to translations.

His mind was universal and broad, capable of finding merit where others found only defects. His memory was astonishing. He was always able to remember the author of a fact, the details of a procedure, or the outcome of a case. He tried to reach the roots of knowledge. When he became interested in kinesiology and planned to publish his book on that subject, he realized that he needed to make calculations which he could not perform unless he mastered higher mathematics. He then, a professor, enrolled himself as a student in mathematics at the State University of Iowa.

Sincerity, the most valuable virtue among men, as Unamuno says, was one of his greatest qualities. Even in his first book (*Orthopaedic Operations*) he surprised the reader by confessing, after the description of every technique, the number of his successes and failures and, by way of explaining his failures saying, humbly: "due to defects of operative technique" or "due to erroneous indication".

Tireless in study and writing, Dr. Steindler started his hospital and teaching day at 7 A.M., even when the lights of his library had still been on at midnight. His seminar notes were kept up to date. He reviewed current world literature, made comments on techniques and papers, and reported scientific meetings which he, "The Chief", attended and at which

he took notes like any student. He was not brilliant or spectacular as a surgeon but his technique was precise, firm, and gentle, neither losing time nor racing against time. He led everybody to think that each operation he performed was an easy procedure, that the convalescence was smooth, and the late results gratifying.

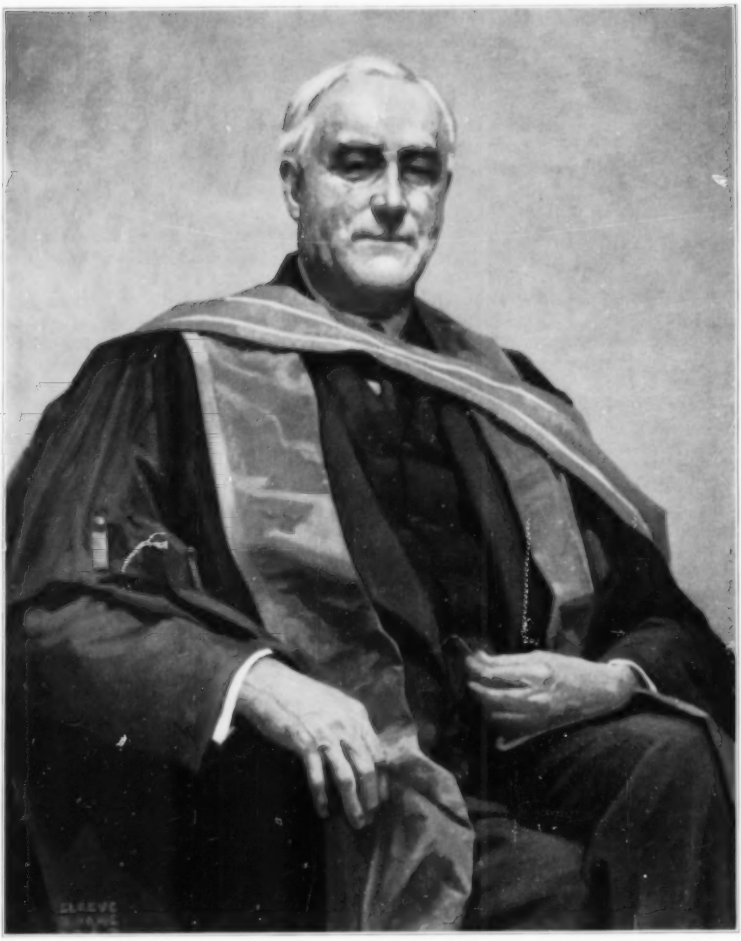
As a husband, he always was alert to the needs or desires of Mrs. Steindler, even to the smallest details. She, in turn, took charge of all things that might disturb him in his work or in his studies. During the war he brought to the States a number of relatives, aiding them to escape from Hitler.

Removed from the discipline of work, research, teaching, and hospital care of patients, his mind relaxed with his friends and students. He enjoyed universal literature, knew history, and was aware of important current events. He played the piano and knew a good deal about music and, as a host, he always tried to be agreeable and to make his guests comfortable. A great sense of humor was one of his characteristics and he told jokes with great pertinence and timeliness.

After the last meeting of The American Academy of Orthopaedic Surgeons that he attended, his former students received news from friends about his serious illness and his determination to continue to correct, despite his hopeless condition, the proofs of his book, *Analysis of Pain in Orthopaedic Entities*. Everybody in the world silently watched the painful death of a MAN, like the slow, inevitable sinking of a boat, among the prayers and screams of the spectators and the desperation of its helpless crew. . . .

That was the way in which he entered immortality.

J. F.



WILLIAM EDWARD GALLIE
1882–1959

The death of William Edward Gallie on September 25, 1959, was a sad blow to all his friends, colleagues, and pupils.

He has been a legendary figure in Canadian surgery for more than half a century. He graduated from the University of Toronto in 1903 and then spent three years in post-graduate training in Toronto and New York. In this period he met the teachers who influenced him profoundly: C. L. Starr and George Peters in Toronto (the latter, a brilliant and versatile surgeon who died young of coronary thrombosis) and Virgil Gibney and Royal Whitman in New York.

When he commenced his career in Toronto in 1906 he soon displayed the inquiring interest in surgical problems which led finally to the original contributions which he made to surgical knowledge. He wrote many papers on a wide variety of subjects but he will be remembered principally for his work on tendon fixation, bone-grafting, and fascial (living) sutures.

His greatest accomplishment was the establishment of a Canadian program of post-graduate training in surgery. When he became Professor of Surgery at the University of Toronto in 1929, the need for training facilities for Canadian surgeons was great, and for many reasons the time was opportune for their establishment. He had the vision to see this clearly and the imagination and the energy to organize such a program. It has proved an immense success. Those who have been trained in the Gallie course in surgery are now themselves leaders in surgery throughout the English-speaking world.

He was a superb leader of men for he had the capacity to win their loyalty and affection as well as command their admiration by his accomplishments. There was nothing drab or routine in his leadership. He made his staff feel that they were members of a team in which every man's work was essential and equally important. Surgery for him was a fascinating art as well as an exacting science, and the pursuit of it was a joyous adventure. His imaginative approach to surgical problems made ward rounds and staff meetings stimulating experiences. They were occasions when the young men around became imbued with his own fire.

He had a warm-hearted interest in the affairs of everyone with whom he came into contact. He always found time to listen to their problems and was ready with sage advice based upon a great experience. He shared his own experiences and success with his colleagues and he was equally interested in their affairs. There was a warm intimacy in his daily contact with his staff and pupils. His University responsibilities were conducted in an atmosphere much like that of a family.

All members of The American Orthopaedic Association, save the very youngest, will remember his strong and handsome countenance and commanding figure (sadly bowed, alas, in recent years). The American Orthopaedic Association was the first scientific body in which he enjoyed membership, and he had a deep loyalty and affection for it. He was wise in council so that his opinion and judgment were often sought. He spoke well, using only the sketchiest of notes or none at all. Clearly and unhurriedly his felicitous phrases unfolded his argument or presentation. Usually, there was a happy quip or anecdote which sharpened the final summary.

The members of The American Orthopaedic Association will remember him best at the meetings held at Greenbrier Hotel (which he thought was the perfect locale for a surgical meeting) with his lovely wife, Louise, who so perfectly complemented his character and sustained him in his work.

In 1951, after his retirement from the Chair of Surgery, he persuaded his friend Mr. R. S. McLaughlin to lay aside a large sum of money to establish the R. Samuel McLaughlin Foundation. This provided funds to finance advanced graduate training and research to young Canadian physicians and surgeons who had been appointed to university teaching posts in order that they might obtain the most advanced training in their particular field. Many members of The American Orthopaedic Association will have met McLaughlin Fellows doing advanced training in orthopaedic surgery.

His contributions to surgical knowledge (nearly all of which are in the field of orthopaedic surgery), his leadership in the training of surgeons, and his strong character and warm personality will keep his memory green. He made a great impression upon the world of surgery of his day, and his influence will long be felt.

The Canadian poet, Professor E. J. Pratt, expressed well the feeling of colleagues, friends, students, and innumerable patients in lines which he wrote for the occasion of the dinner given to Dr. Gallie in June 1947 when he retired from the Chair of Surgery:

"A master of creative surgery,
He treats, rebuilds, shows others how to heal,
And led the cripples from the wards to feel
The sunlight in their new-found liberty."

R.I.H.

News Notes

The Twenty-seventh Annual Meeting of **The American Academy of Orthopaedic Surgeons** will be held at the Palmer House, Chicago, Illinois, January 23 to 28, 1960.

The Fifteenth Annual Meeting of the **American Society for Surgery of the Hand** will be held Friday and Saturday, January 22 and 23, 1960, at the Palmer House, Chicago, Illinois. The program is as follows:

January 22

Extension of the Distal Phalanx of the Thumb. R. M. MacFarlane, M.D., London, Ontario, Canada, and Sumner L. Koch, M.D., Chicago, Illinois.

An Experimental Study of Digital Flexor-Tendon Healing. W. K. Lindsay, M.D., Toronto, Ontario, Canada.

Observations in Roller Injuries: An Experimental Study. John P. Adams, M.D., and Francis D. Fowler, M.D., Washington, D. C.

Ischemia Resulting from Tourniquet Application to the Extremity. F. X. Paletta, M.D., St. Louis, Missouri.

Experience with Cross-Finger Pedicle Flaps. J. W. McNichol, M.D., and Orville J. Mirehouse, M.D., Hamilton, Ontario, Canada.

Surgery of the Arthritic Hand. Lee R. Straub, M.D., Rolla D. Campbell, Jr., M.D., and John L. Sharbaro, Jr., M.D., New York, N.Y.

Complicated Syndactyly: "Timing" and "Procedures" for Correction. W. H. Frackelton, M.D., Milwaukee, Wisconsin.

Tendon-Grafting for Division of Flexor Profundus. Guy Pulvertaft, F.R.C.S., Derby, England.

The Appearance of Boeck's Sarcoid in the Hand. Robert E. Carroll, M.D., and Meyer Alpert, M.D., New York, N.Y.

Osteosarcoma Superimposed upon Osteitis Deformans in the Phalanges of the Hand: A Solitary Case Report. Benjamin W. Drompp, M.D., Detroit, Michigan.

Management of Fractures of the Greater Multangular. Lee J. Cordrey, M.D., Tampa, Florida.

Restoration of Hand Function by the Use of Partial or Total Prosthetic Replacement. Alfred B. Swanson, M.D., Grand Rapids, Michigan.

January 23

Composite Graft of Bone and Tendon in Complete Construction of a Digit. Herbert Conway, M.D., New York, N. Y.

Opposition of the Thumb and Its Restoration. T. Campbell Thompson, M.D., and Bernard Jacobs, M.D., New York, N. Y.

Extensor Habitus. William L. White, M.D., Pittsburgh, Pennsylvania.

A Review of 135 Cases of Tendon Lacerations in the Hand and Wrist. George F. Crikelair, M.D., New York, N. Y.

Flexor-Tendon Ruptures in the Forearm and Hand. Joseph H. Boyes, M.D., and James N. Wilson, M.D., Los Angeles, California, and James W. Smith, M.D., New York, N. Y.

Discussion of Preceding Papers on Tendon Surgery. Question-and-Answer Period. Guy Pulvertaft, F.R.C.S., Derby, England.

Dr. Walter Ehalt, Graz, Austria, writes concerning the activities of the **Austrian Orthopaedic Society,** 1958-1959: During 1958 and 1959, there were as usual four scientific meetings to discuss such various subjects as tuberculosis, scoliosis, and apparatus. The 1957 Annual Meeting was held jointly with the Society of Traumatology and the Society of Physical Medicine in Bad Hall. At this meeting there was a discussion of tuberculosis of soft tissues and the influence of hot Jodin springs. In 1958, the Annual Meeting was held in Bad Gastein; here aseptic necrosis of various bones, the effect of underwater therapy, and very strong radioactive waves were discussed. The *Stollen* in Gastein, where this type of treatment is done, was visited. In 1959, the Meeting was held in Innsbruck-Tyrol; the topic for discussion was affection of the knee joint, excluding tuberculosis. At this meeting there were many visitors from all over Europe. The discussions on osteochondritis dissecans, patellectomy, and joint injuries were very interesting. The President of the Society for all these years was Prof. Dr. Erlacher of Vienna.

An **International Conference of Surgeons** will be held in Tel Aviv and Jerusalem, Israel, May 21, 22, and 23, 1960, after the Biennial International Congress of the International Col-

lege of Surgeons in Rome, May 15, 16, 17, and 18, 1960. The conference in Israel will be held under the auspices of the Israel Minister of Health and will include a number of symposia on different surgical fields. The conference will deal in particular with medical problems of young nations in Asia and Africa which have gained statehood in the past decade. After the conference, visits to Israel's hospitals and medical establishments will be arranged. A sightseeing tour of all of Israel is also available. Detailed information can be obtained from the International Secretariat, International College of Surgeons, 1516 Lake Shore Drive, Chicago, Illinois.

The study by the **Committee on Bio-Mechanics and Implants** of the behavior of implants used in bone surgery is under way. Success of the project depends largely on the number of implants submitted to the Committee. Failing implants discovered at surgery or in the *laboratory, along with specimens* of the surrounding tissue, should be directed to: Committee on Bio-Mechanics and Implants, The American Academy of Orthopaedic Surgeons, 116 South Michigan Avenue, Chicago 3, Illinois. The Committee requests that information be supplied as to the time elapsing between insertion and failure of implants and, when possible, that roentgenograms be supplied.

There has been a change in the dates scheduled for the 1960 Meeting of the **Mid-Central States Orthopaedic Society.** The meeting will be held on Friday April 8 and for one-half day on Saturday April 9, 1960, in Wichita, Kansas. For additional information, write H. O. Marsh, M.D., *Secretary*, 3244 East Douglas, Wichita 8, Kansas.

Symposium on Parathyroid Research Trends

A symposium devoted entirely to the problems of parathyroid physiology and malfunction will be held on the Rice Institute campus, Houston, Texas, on February 3 to 6, 1960. All interested persons are invited to attend. There are no registration fees connected with attendance at *the conference*. However, pre-registration is requested in order that appropriate facilities can be arranged. Further information and application forms can be obtained by writing to Dr. Roy V. Talmage, Department of Biology, Rice Institute, Houston 1, Texas.

M. D. Anderson Hospital and Tumor Institute of the University of Texas, Houston, Texas, will hold the **Fourteenth Annual Symposium on Fundamental Cancer Research,** "Cell Physiology of Neoplasia", February 25 to 27, 1960. The various subjects to be discussed include morphology of cells, behavior of organelles, submicroscopic structures, cytochemistry, growth phenomena, and biochemical properties of cells. Further information may be obtained by writing: Editorial Office, the University of Texas M. D. Anderson Hospital, Texas Medical Center, Houston 25, Texas.

A **$400,000 George W. Merck Memorial Loan Fund** has been established by The Merck Company Foundation to help to meet an important need for financial aid to interns and residents. The fund will assist deserving interns and residents to seek the best possible postgraduate training in teaching hospitals before entering practice. It is estimated that sixty to 100 young doctors will benefit each year from the fund. The eighteen medical schools participating are associated with the following universities: Boston, California, Chicago, Columbia, Cornell, Harvard, Illinois, Johns Hopkins, New York, Northwestern, Pennsylvania, St. Louis, Tufts, Vanderbilt, Vermont, Virginia, Washington (St. Louis), and Yale. Administration of the fund will be by the deans of the medical schools, who will have complete freedom in selection of recipients. Initial payments to the eighteen schools have been completed so that funds will be available in 1959.

The Eighth Congress of the **Pan-Pacific Surgical Association** will be held in Honolulu, Hawaii, September 28 through October 5, 1960. Further information and brochures may be obtained by writing to Dr. F. J. Pinkerton, Director General of the Pan-Pacific Surgical Association, Suite 230, Alexander Young Building, Honolulu 13, Hawaii.

Irregularly calcified lesion in the medullary cavity with smooth scalloping of the endosteal surface of the cortex. Lesion occupies the proximal half of the shaft extending to the region of the tuberosities. Radiograph made on Kodak Royal Blue, fastest available medical x-ray film, designed expressly to provide maximum information with minimum exposure.

EXPLORATORY FENESTRATION

of left humerus with partial removal by curettement of a lesion in the marrow cavity.

Radiographs, preoperative and postoperative. Color photographs, showing essential steps in the surgery.

1. Incision at anterolateral aspect of the arm near insertion of the deltoid muscle.

(Turn page for additional illustrations)

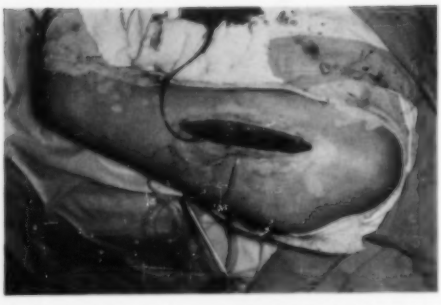
Exploratory Fenestration (Continued)

The color photographs reproduced on this and the preceding page were made on Kodak Ektachrome roll film. 2 x 2 slides, also, were available to the surgeon for teaching and review, as well as black-and-white prints for files—definitive, fully objective materials *for use any time, anywhere!*

2. Small cortical window has been made in the humerus showing the underlying pathologic lesion.

3. Cortical window has been enlarged and the lesion in the marrow cavity partially curetted.

Note: Kodak Ektachrome roll film, used to make the illustrations for this picture sequence, may also be obtained for miniature cameras and sheet-film cameras.



4. Wound prior to closure. Two polyethylene tubes in place, one for suction, the other for insertion of antibiotics.

5. Technician preparing to radiograph patient in surgery to show extent of dissection in marrow cavity. Radiographs read wet, gave surgeon quick progress picture.

Postoperative radiograph made week following exploratory fenestration. Examination of resected tissue showed lesion to be a chondrosarcoma.

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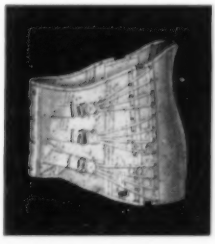

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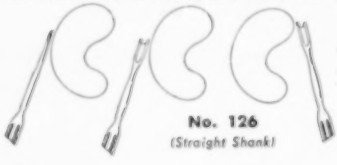

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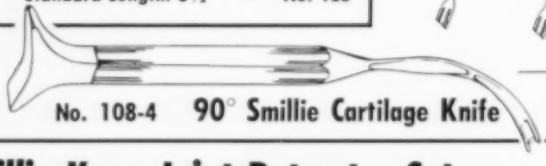

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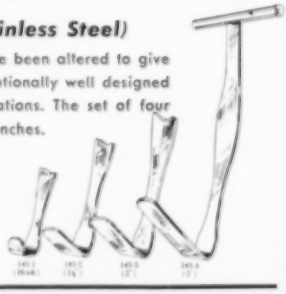

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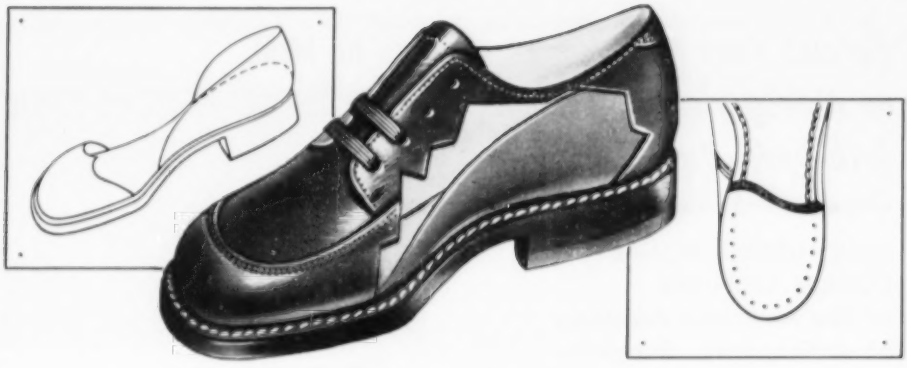

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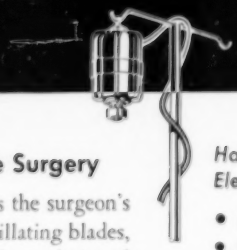

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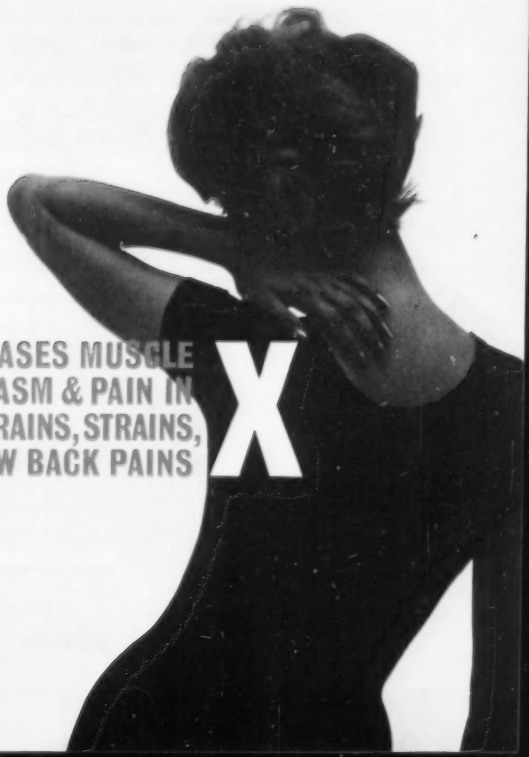

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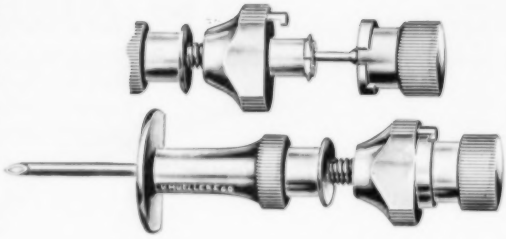

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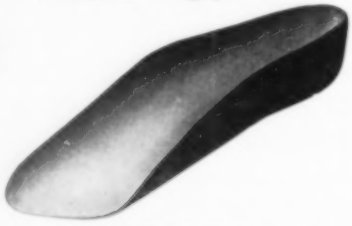

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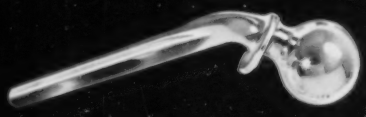

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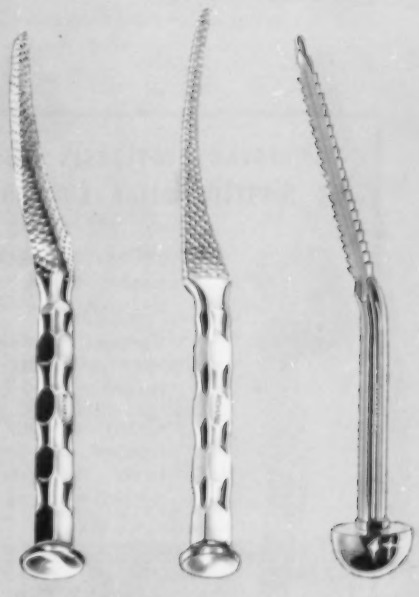

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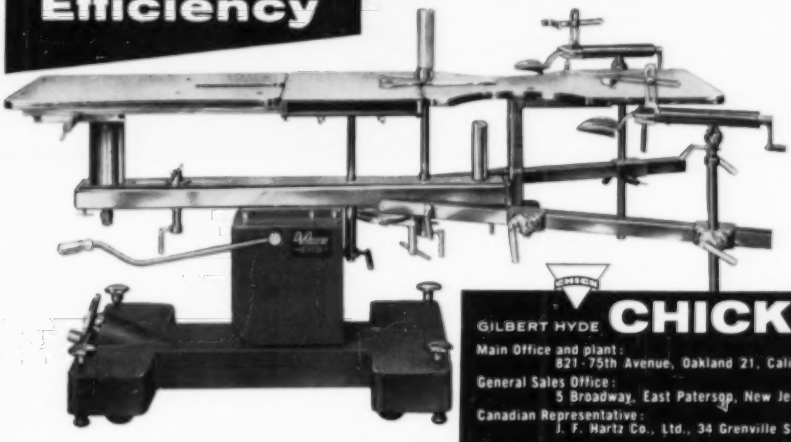

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